Enhancing Urban Resilience Capacities: An Analytic Network Process-based Application

Environmental and Climate Technologies
2021, vol. 25, no. 1, pp. 1270–1283
https://doi.org/10.2478/rtuect-2021-0096
https://content.sciendo.com

Enhancing Urban Resilience Capacities: An Analytic Network Process-based Application

Giulia DATOLA[1*], Marta BOTTERO[2], Elena DE ANGELIS[3]

[1–3]*Interuniversity Department of Regional and Urban Studies and Planning, Politecnico di Torino, Viale Mattioli 39, Torino, Italy*

***Abstract* – The current urban challenge is enhancing, maintaining and improving the urban resilience of cities. However, how can cities as complex and adaptive systems be or become resilient? There are specific capacities/qualities that urban systems should have to enhance and maintain their resilience (e.g. redundancy, resourceful, robustness, etc.). Different studies list and describe these capacities in literature, underling also to which urban dimension (e.g. economy, society) they are referred. However, there is a lack of quantitative assessment of these capacities. As well, the analysis of which degree different urban components can enhance and maintain these capacities. Based on the socio-ecological approach of urban resilience, this study proposes the application of multicriteria analysis (MCA) to evaluate which degree the different urban components can support the enhancement and the maintenance of the specific urban resilience capacities. The proposed framework is an indicators-based method that includes a multidimensional set of urban resilience indicators and the set of urban resilience capacities. In detail, the Analytic Network Process (ANP) has been selected according to its ability to consider the mutual interconnections of the evaluation elements. Moreover, a multidisciplinary panel of experts is asked to weigh the importance of the different urban components in enriching the different urban resilience qualities. The final result is a set of priorities that assess the relative importance of each urban component about a specific urban resilience capacity. The illustrated application is a preliminary pilot case study that quantifies the possibility of quantitatively assessing the urban resilience capacities. In detail, this application refers to a more complex and comprehensive evaluation approach that combines MCA with the System Dynamics Approach (SDM). Therefore, the next step of this research will concern the aggregation and the employment of the obtained priorities in the abovementioned approach to correlate the urban resilience performance with the urban capacities.**

***Keywords* – Analtyic Network Process (ANP); decision making support; multicriteria analysis; urban systems**

1. INTRODUCTION

Planning for resilient cities is the critical issue of the current urban agenda [1]. This interest is since cities are exposed to different hazards and stresses, both natural and human-made [2]. Thus, various actions, campaigns and policies have been developed to enhance, improve and maintain the urban resilience of cities [3], [4]. The final target is making cities that can respond, adapt, and transform facing these pressures [5]. Within this perspective, the assessment of urban resilience becomes essential. Several tools and methods have been

* Corresponding author.
E-mail address: giulia.datola@polito.it

developed to assess urban resilience, especially during the last decade [6]–[8]. The main interest of these frameworks is to evaluate the current urban resilience performance. Suares and colleagues [9] propose an indicators-based model to assess the urban resilience performance of different fifty Spanish cities. Moreover, they develop also a GIS map to compare the different cities according to their resilience performance. Moghadas and colleagues also provide an evaluation approach based on the integration of the Analytic Hierarchy Process (AHP) and TOPSIS that belong to the multicriteria analysis (MCA) techniques. The evaluation objective is to compare the resilience performance of the different regions of the city of Teheran [9].

However, despite the current interest in proposing new evaluation frameworks and tools to support the decision-making process in urban resilience enhancement, only a few of the proposed methods include the urban resilience capacities in the general evaluation framework. It is possible to cite some peculiar case studies related to this purpose. Firstly, the Rockefeller Foundation presents the city resilience index and the city resilience framework [3], [10]. In these documents, the urban resilience capacities are in-depth listed and described. Moreover, the city resilience index describes the relations between urban resilience indicators and urban resilience capacities. Secondly, the proposed method by Fox-Lent provides a matrix to describe the interconnection between urban variables and urban resilience capacities [11]. This approach has also been implemented by Sharifi and Yamagata [12]. The most recent and innovative framework that include urban resilience capacities is proposed by Wardekker and colleagues [13]. It aims to evaluate how much these capacities are highlighted in urban policy, to support policymakers and decision-makers in the decision process [13], [14]. However, it is possible to recognise the lack in quantitatively assessing urban resilience capacity by analysing how urban components can support the enhancement and maintenance of these capacities.

In this context, the present paper proposes the employment of the Analytic Network Process (ANP) [15], [16] to evaluate the relative importance of different urban components about urban resilience capacities. The proposed method includes a multidimensional set of urban resilience indicators and the set of urban resilience capacities. Moreover, a multidimensional panel of experts is engaged in this preliminary application to verify the proposed evaluation framework's usefulness and underline its weaknesses and strengths. Furthermore, this application refers to a more comprehensive and complex evaluation framework that combines the System Dynamics Model (SDM) with the MCA to assess urban resilience within its multidimensionality, complexity and dynamic behaviour over time [17], [18]. Please see [17], [18] for more details of the complete approach.

The paper is structured into these sections: Section 2 briefly describes the concept of urban resilience within its main characteristics and capacities, Section 3 describes the application of the proposed framework to assess the relative importance of urban components in enhancing and maintaining urban resilience capacities, Section 4 illustrates the different evaluations obtained by the various experts, Section 5 discusses the obtained results and the Section 6 addresses the conclusion and reflections for the future development of research.

2. CONCEPTUALISING THE CONCEPT OF URBAN RESILIENCE

2.1 Definition and Characteristics of the Urban Resilience Concept

The concept of urban resilience has been analysed by several disciplines, such as climate change [19] and disaster risk management [20]. Moreover, it has also been discussed in academic and political contexts [21]. This concept has thus many definitions, with different meanings. Moreover, there are two main approaches to conceptualising the resilience concept in literature. The first approach concerns engineering resilience, which refers to the capacity to return to the previous equilibrium, or rather 'bounce back' [22]. The second approach belongs to socio-ecological resilience [23]. It concerns the ability of the system to transform itself, supporting and accepting the change of the system. This specific approach has also been interpreted as 'evolutionary resilience' [21].

In detail, the urban resilience concept that can be described as the ability of urban systems with their constituents to adapt, transform and change in reference to shocks and stresses [22] is grounded on the socio-ecological approach of resilience. Thus, it is possible to list the main peculiarities of the urban resilience concept. Firstly, urban resilience is a multidimensional and multifaceted phenomenon. In literature, five urban dimensions have been identified to implement urban resilience [24]. These dimensions are

- Physical;
- Natural;
- Economic;
- Institutional;
- Social.

Secondly, there are specific characteristics/capacities that urban systems should have to enhance urban resilience, according to the socio-ecological approach. Section 2.2 lists and describes these capacities.

2.2. Urban Resilience Capacities

As above mentioned, urban systems should have some specific characteristics to enhance and maintain their resilience. In detail, these capacities address different urban components that refer to all the urban resilience dimensions. This section aims to describe them and specify which dimension of urban resilience they are referred. Table 1 lists and describes the urban resilience capacities. This list is the result of an in-depth literature review that combines the resilience capacities described both in different resilience approaches [25] and in various urban resilience campaigns (for more details, please see [26]).

TABLE 1. LIST OF URBAN RESILIENCE CAPACITIES

Capacity	Description	Sources
Robustness	It can be defined as the ability of the urban system to resist external stresses and disturbances. Thus, it is strictly related to the 'strength'. Moreover, it also concerns a robust design that aims to anticipate potential failures of the system. Robust systems concern the well-conceived, constructed and managed physical assets. In detail, the characteristic of robustness deals with the infrastructure dimension of resilience.	[27]–[32]
Redundancy	It can be described as 'the existence of several functionally similar components so that the system does not fail when one of the components fail'. It deals with the existence of backup systems.	[28]–[33]
Inclusivity	It concerns communities' engagement to include the most vulnerable groups, emphasising the necessity of broad consultation. In detail, inclusivity concerns both the social and the economic dimensions of resilience.	[30], [31]
Reflective	It addresses the ability of the system to accept the uncertainty and the changes. Reflective systems have mechanisms that permit them to continuously evolve themselves, also modifying standards and norms according to emerging evidence.	[34]
Resourceful	It concerns the ability of people and institutions to rapidly change the way to achieve their goals when stresses occur. Thus, this capacity includes also the capacity of	[34], [35]

	predicting future conditions. Moreover, it is fundamental to improve the ability of the city to restore the functionality of critical systems.	
Integration	This capacity mainly concerns the decision-making process, and it is strictly related to the governance dimension of resilience. Integration aims at promoting decision-making according to shared objectives. Moreover, the principles on which the integration is grounded can be described as '*the exchange of information between systems allows them to function collectively and quickly respond through shorter response cycles across the city'*.	[30], [31], [34], [36]
Flexibility	This capacity is referred to the ability of the urban system to perform essential tasks under a wide range of conditions. Furthermore, it highlights the capacity of the urban system to introduce or modify a new way to reach the necessity. Therefore, flexibility addresses the ability of the system to transform, evolve and adapt in response to changes. For instance, it can support and implicate modularity in the infrastructure approach and ecosystem management.	[37]

3. METHODOLOGY

3.1. Definition of the Multidimensional Set of Indicators

As mentioned before, the proposed method is an indicator-based model. It includes both a multidimensional set of urban resilience indicators and a list of urban resilience capacities. The first aim is to evaluate how different urban components can support the enrichment of urban resilience capacities.

The first methodological step concerns identifying the multidimensional set of indicators referred to urban resilience. Table 2 lists the selected indicators. Different frameworks available in the literature [12], [24], [38]–[40] have been combined to compare the dimensions of urban resilience and the urban resilience indicators with the related urban resilience capacities.

TABLE 2. LIST OF INDICATORS WITH THEIR RELATION TO URBAN RESILIENCE CAPACITIES

Urban resilience Dimension	Indicator	Description	Unit	Capacity	Source
Society	S.1. Vulnerable people	Portion or number of vulnerable people. (It includes older people, dependency rate and not graduated people)	[% – num.]	Inclusivity	[39]
	S.2. Health coverage condition	The ratio between health demand and health offer (patient per 1.000 inhab./ bed per 1.000 inhab.)	[%]	Inclusivity Resourceful	[39]
	S.3. Educational equity	The ratio of the population with a college education	[%]	Inclusivity Resourceful	[39], [41]
	S.4. Civic engagement	Persons involved in civic organization per 10.000 inhabitants	[num.]	Inclusivity Resourceful, Integrated	[39], [42], [43]
Economy	Ec.1. Economic active people	People with a job	[num.]	Resourceful	[39]
	Ec.2.	Average of the equalised disposable household income	[€]	Inclusivity Resourceful	[39], [42]

	Equalised Disposable household income				
	Ec.3. Economic mixitè	Diversity index to measure the economic mixité in terms of economic activities	[0–1]	Resourceful, Redundancy	[39]
Environment	En.1. Green area	Total of surface covered by green and permeable area	[Hectares]	Resourceful	[43]
	En.2. Soil Consumption	Total of urbanised surface	[Hectares]	Resourceful	[43]
	En.3. Diversification in energy supply	Different sources of energy	[0–1]	Redundancy, Resourceful, Flexiblity	[43]
Infrastructure	In.1. Main roads	Extension of main roads	[km linear]	Redundancy, Resourceful, Flexiblity	[39]
	In.2. Housing affordability	Number of family with private house / percent of house ownership	[num.]	Inclusivity	[39]
	In.3 Public transportation accessibility	Number of passengers of public transport/year	[num.]	Inclusivity, Redundancy	[39]
	In.4. Private transportation accessibility	Percentage of population with a vehicle/year	[%]	Inclusivity	[39]
Governance	G.1. Number of participative processes	Number of participative processes	[num.]	Inclusivity, Integrated	[39]
	G.2. Climate action plan	The presence or not of the climate action plan	[qual.]	Redundancy, Resourceful, Flexiblity	[39]
	G.3. Risk assessment	Presence or not of risk assessment in the municipal plan	[qual.]	Redundancy, Resourceful, Flexiblity	[39]

As it is possible to notice in Table 2, most of the indicators are related to many urban resilience capacities. For instance, the indicator 'G.2. climate action plan' can contribute to redundancy, resourceful and flexibility capacities. Therefore, the enhancement of these urban resilience capacities is due to the combination of multidimensional urban components. For example, the capacity of inclusivity depends on economic, society and governance factors.

3.2. Analytic Network Process

The present paper proposes the ANP to construct the evaluation framework to assess the relative importance of different urban components in urban resilience capacities. This choice has been made following the ability of the ANP to analyse decision problems with a high level of complexity. The ANP can represent the decision problem as a network, underlying thus the mutual interdependencies among the evaluation variables.

For this reason, the ANP is considered as the evolution of the Analytic Hierarchy Process (AHP) [44]. In detail, the ANP is grounded on two main methodological principles:

- The decision process is analysed and represented through a network structure;
- The pairwise comparison is used to establish and weigh the system's relationships.

In detail, four methodological steps are required to develop the ANP model:

1. Structuring the decision process. In this phase, the evaluation network has to be developed, identifying its clusters within their relative nodes, according to the methodological framework [44];
2. The pairwise comparison. It is applied to establish the relative importance of the different elements according to a specific component of the network. The comparison is processed following the Saaty's fundamental scale [16], [45], which is a 9 points scale. In detail, the value 1 stands for equal importance of the two elements, whereas the value 9 indicates that a component is more important than the other;
3. The development of the supermatrices. This phase concerns the development of three supermatrices:

- The unweighted matrix that includes all the eigenvectors determined from the pairwise comparison matrixes;
- The weighted matrix that is obtained by the combination of the initial matrix with the pairwise comparison;
- The final matrix.

4. Performing of the final priorities. The last step of the ANP concerns the calculation of the weighted supermatrix and the final supermatrix. The final supermatrix is performed to get the final set of weights that distinguish the different elements. In detail, the final priority is calculated through the Eq. (1).

$$\lim_{k \to \infty} W^k \tag{1}$$

4. APPLICATION

4.1. Structuring the Evaluation Network

As discussed in the previous section, the ANP has been chosen according to its capacity to consider the mutual interdependences among the identified indicators.

Following the methodology, the indicators and the urban resilience capacities are organised into clusters and nodes. Fig. 1 shows the ANP network developed for this assessment. In detail, the network is organised into six clusters that represent respectively

- Urban resilience capacities;
- The social dimension;
- The environment dimension;
- The infrastructure dimension;
- The governance dimension;
- The economy dimension.

At the same time, the specific indicators and the capacities have been identified as nodes in the corresponding cluster.

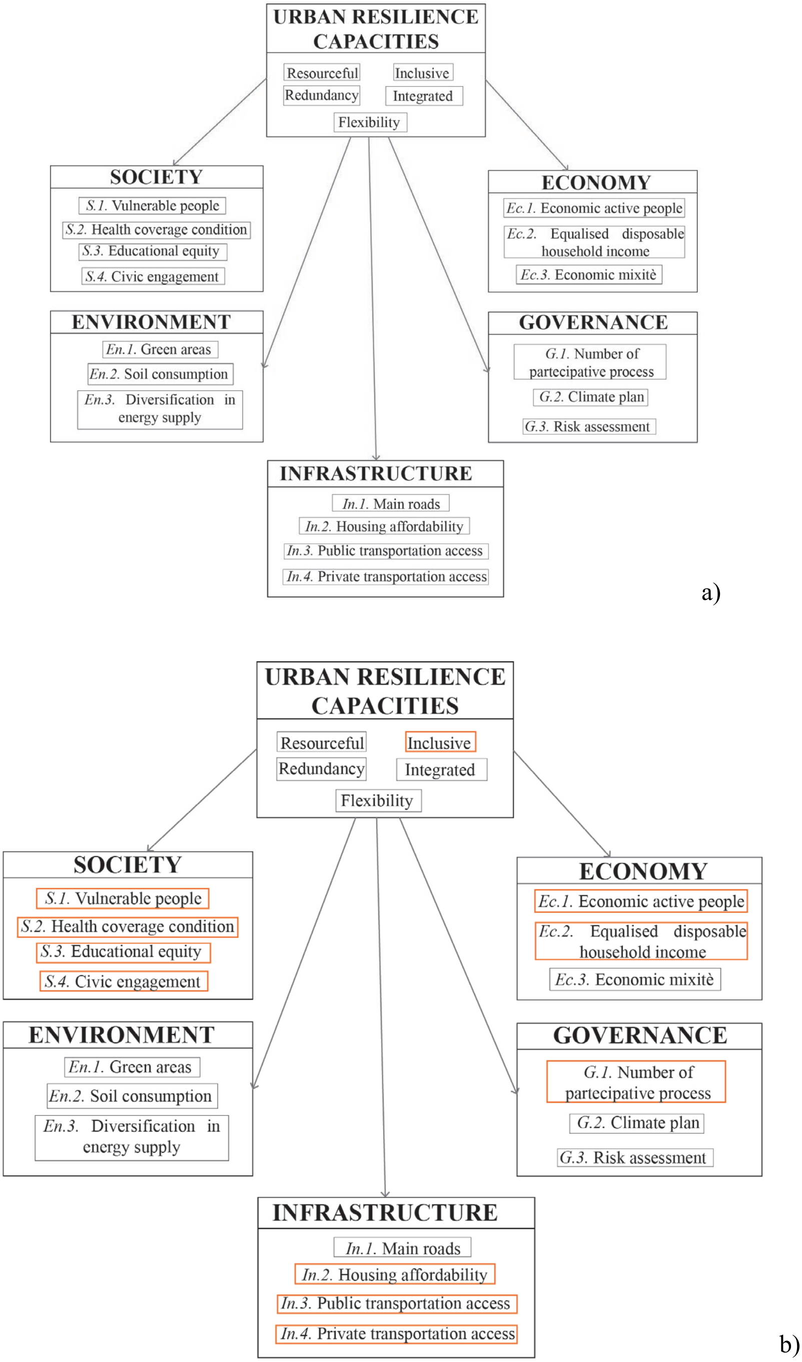


Fig. 1. ANP network of a) urban resilience capacities and indicators, modelled through *SuperDecision* software; b) representation of relationships between the inclusive capacity with other nodes.

This network has been constructed according to the information listed in Table 2. For example, Fig. 1(b) illustrates that the row that runs among the cluster of urban resilience capacities and the society cluster represents the relationships between the nodes of inclusive with all nodes of the society social cluster. The row between the cluster of urban resilience capacities and the economy cluster also symbolises the relationships between the inclusive node and the nodes of *Ec.1.* Economic active people and *Ec.2.* Equalised Disposable household income. Thus, through this organisation, it is possible to determine the importance of each indicator according to each urban resilience capacity. The following section illustrates the weighting process.

4.2. The Pairwise Comparison and the Determination of the Weights

As mentioned in Section 3.2, the ANP requires a pairwise comparison to establish the priorities between the elements involved in the evaluation. For this application, a multidimensional panel of experts is asked to assess the relative relevance of the selected indicators according to the considered urban resilience capacities. In detail, the board is composed of an expert in social dynamics, an expert in the environmental field and an expert in economic evaluation. In detail, experts in the field of economy, society and environment are selected to verify that the primary relations among the indicators and urban resilience capacities have been highlighted. Experts are also involved in this preliminary insight to assess the proposed approach's usefulness and give feedback about its strengths and weaknesses. In general, following the ANP methodology, the pairwise comparison is structured into two main steps: (1) the pairwise comparison among the clusters and (2) the pairwise comparison among nodes. Thus, experts were first asked to evaluate the relative importance of the different urban resilience dimensions regarding urban resilience capacities. As an example, Table 3 shows the questionnaire for the cluster comparison, compiled by an expert in the environment field. It can be addressed that relative importance has been given to the environmental dimension. However, also the governance dimension is considered relevant concerning urban resilience capacities.

TABLE 3. PAIRWISE COMPARISON BETWEEN THE CLUSTER OF URBAN RESILIENCE DIMENSION WITH THE RESPECT TO URBAN RESILIENCE CAPACITIES COMPILED BY THE ENVIRONMENT EXPERT

Economy	9	8	7	6	5	4	3	2	1	2	**3**	4	5	6	7	8	9	Environment
Economy	9	8	7	6	5	4	3	2	1	2	**3**	4	5	6	7	8	9	Governance
Economy	9	8	7	6	5	4	**3**	2	1	2	3	4	5	6	7	8	9	Infrastructure
Economy	9	8	7	6	**5**	4	3	2	1	2	3	4	5	6	7	8	9	Society
Environment	9	8	7	6	5	4	**3**	2	1	2	3	4	5	6	7	8	9	Governance
Environment	9	8	7	6	5	4	**3**	2	1	2	3	4	5	6	7	8	9	Infrastructure
Environment	9	8	7	6	**5**	4	3	2	1	2	3	4	5	6	7	8	9	Society
Governance	9	8	7	6	5	4	**3**	2	1	2	3	4	5	6	7	8	9	Infrastructure
Governance	9	8	7	6	**5**	4	3	2	1	2	3	4	5	6	7	8	9	Society
Infrastructure	9	8	7	6	5	4	**3**	2	1	2	3	4	5	6	7	8	9	Society

Secondly, experts are asked to perform the pairwise comparison for the nodes. Table 4 illustrates the pairwise comparison of the social nodes according to the inclusivity capacity. Table 4 underlines the importance of the 'health coverage condition' indicator referred to inclusivity capacity. Table 5 describes the comparison among infrastructure nodes according to the inclusivity. Whereas, Table 5 highlights how the indicator referred to the 'housing affordability' is considered much more important than others about inclusivity capacity by the expert in economic evaluation.

TABLE 4. PAIRWISE COMPARISON BETWEEN SOCIETY NODES IN REFERENCE TO THE INCLUSIVITY COMPILED BY THE EXPERT IN SOCIAL DYNAMICS

Civic engagement	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Educational equity
Civic engagement	9	8	7	6	5	4	3	2	1	2	3	4	**5**	6	7	8	9	Health coverage condition
Civic engagement	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Vulnerable people
Educational equity	9	8	7	6	5	4	3	2	1	2	3	4	**5**	6	7	8	9	Health coverage condition
Educational equity	9	8	7	6	5	4	3	2	**1**	2	3	4	5	6	7	8	9	Vulnerable people
Health coverage condition	9	8	7	6	5	4	3	**2**	1	2	3	4	5	6	7	8	9	Vulnerable people

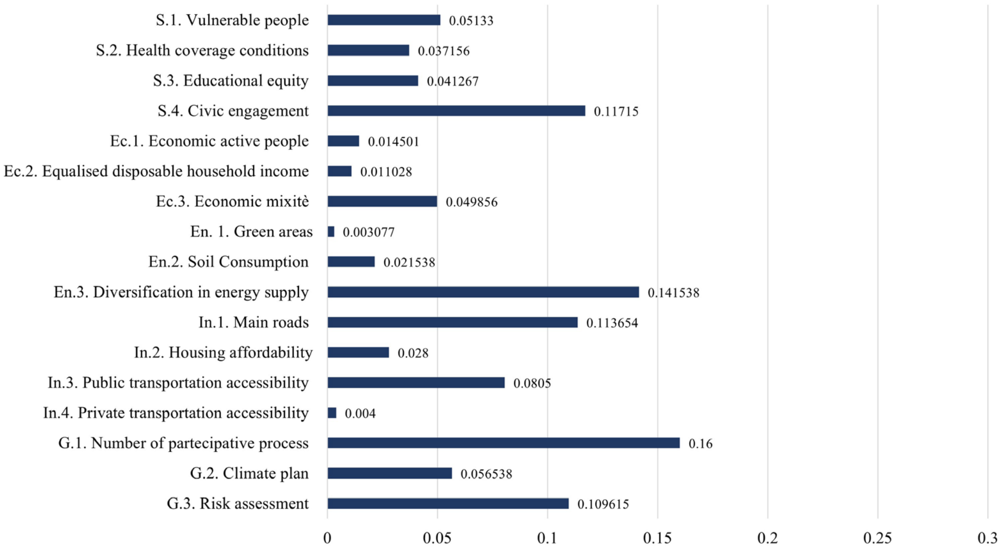
TABLE 5. PAIRWISE COMPARISON BETWEEN INFRASTRUCTURE NODES IN REFERENCE TO THE INCLUSIVITY COMPILED BY THE EXPERT IN ECONOMIC EVALUATION

Housing affordability	9	8	7	**6**	5	4	3	2	1	2	3	4	5	6	7	8	9	Private transportation accessibility
Housing affordability	9	8	7	6	5	**4**	3	2	1	2	3	4	5	6	7	8	9	Public transportation accessibility
Private transportation accessibility	9	8	7	6	5	4	3	2	1	2	3	**4**	5	6	7	8	9	Public transportation accessibility

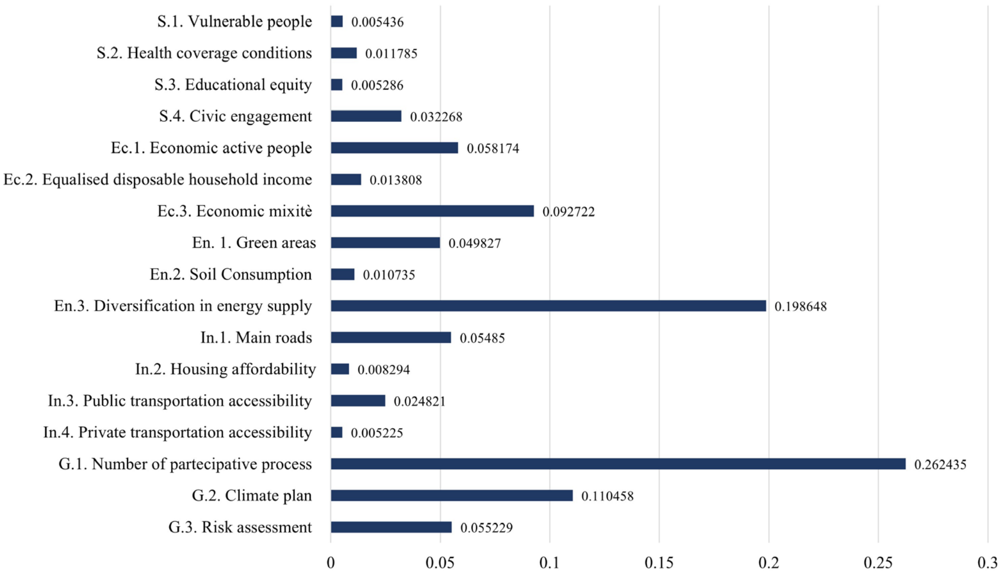
In detail, it is fundamental to underline that these pairwise comparisons are performed according to the influences and interdependencies recognised in the network. The following sections illustrate the result of the weighting process developed by the different experts.

5. DISCUSSION OF RESULTS

This section discusses the obtained results to compare the preferences expressed by the different experts.


S.1. Vulnerable people
S.2. Health coverage conditions
S.3. Educational equity
S.4. Civic engagement
Ec.1. Economic active people
Ec.2. Equalised disposable household income
Ec.3. Economic mixitè
En. 1. Green areas
En.2. Soil Consumption
En.3. Diversification in energy supply
In.1. Main roads
In.2. Housing affordability
In.3. Public transportation accessibility
In.4. Private transportation accessibility
G.1. Number of partecipative process
G.2. Climate plan
G.3. Risk assessment
0.05133
0.037156
0.041267
0.11715
0.014501
0.011028
0.049856
0.003077
0.021538
0.141538
0.113654
0.028
0.0805
0.004
0.16
0.056538
0.109615
0
0.05
0.1
0.15
0.2
0.25
0.3

a)


S.1. Vulnerable people
S.2. Health coverage conditions
S.3. Educational equity
S.4. Civic engagement
Ec.1. Economic active people
Ec.2. Equalised disposable household income
Ec.3. Economic mixitè
En. 1. Green areas
En.2. Soil Consumption
En.3. Diversification in energy supply
In.1. Main roads
In.2. Housing affordability
In.3. Public transportation accessibility
In.4. Private transportation accessibility
G.1. Number of partecipative process
G.2. Climate plan
G.3. Risk assessment
0.005436
0.011785
0.005286
0.032268
0.058174
0.013808
0.092722
0.049827
0.010735
0.198648
0.05485
0.008294
0.024821
0.005225
0.262435
0.110458
0.055229
0
0.05
0.1
0.15
0.2
0.25
0.3

b)

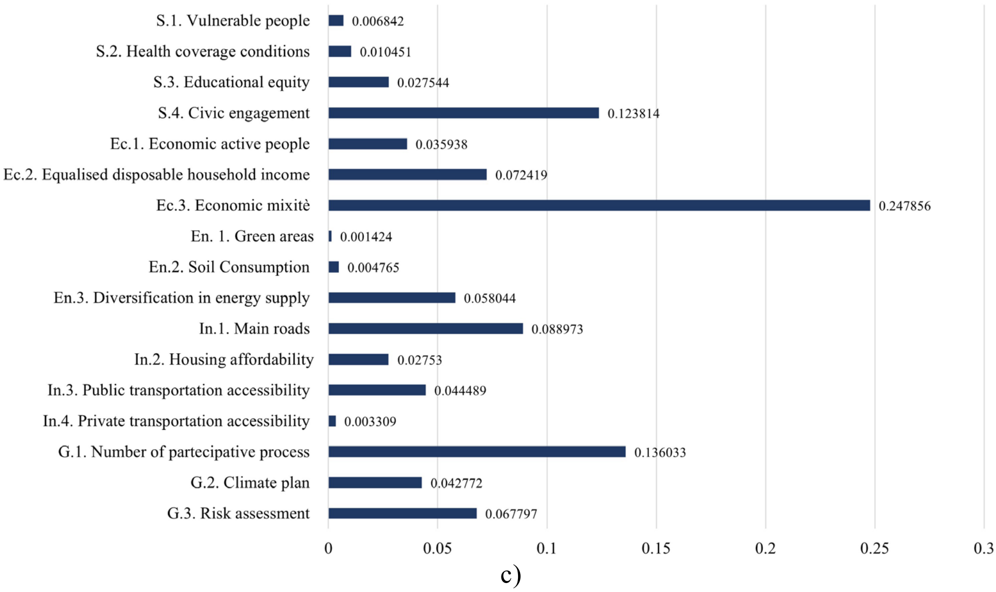


Fig. 2. Final priorities of a) social expert; b) environment expert; c) economic expert.

Fig. 2 illustrates the final priorities of the considered indicators (Table 2), obtained by the pairwise comparison of the different involved experts. These priorities permit to get the supermatrices mentioned in Section 3.2. Thus, it is possible to comment on the performed results, focusing on their similarities and discordances. It is important to recall these priorities consider the pairwise comparison among clusters and nodes about urban resilience capacities.

For instance, all experts give great importance to the indicators referred to the governance dimensions, or rather 'G.1. The number of participative processes', 'G.2. Climate plan' and 'G.3. Risk assessment'. The indicator related to the 'En.3. Diversification in energy supply' has been considered very relevant by the economic and environmental experts. In contrast, the social expert gives to it less importance. As well, for the indicator related to 'Ec.3. Economic mixite'. Moreover, all the experts consider the indicators 'In.3. Public transportation accessibility and 'In.4 Private transportation accessibility' as less important, related to urban resilience capacities. They also evaluate similarly the indicator of 'S.4. Civic engagement', according to the importance given to the indicator 'G.1. The number of participative processes'.

However, also some differences can be recognised above these similarities. Firstly, the difference in the evaluation of the 'En.1. Green areas' can be highlighted and the discrepancy in the assessment of the 'En.2. Soil consumption'. These indicators have been evaluated as very relevant by the environmental expert.

In contrast, the social and the economic experts evaluate them as less important about urban resilience capacities. The same observation can be made for the indicators 'Ec.2. Equalised disposable household income' that has been considered very important by the economic expert and less important by the social and the environmental experts.

6. Conclusion

This paper proposes the application of the ANP to assess the importance of different urban resilience indicators about urban resilience capacities. This application is a preliminary insight into evaluating urban resilience capacities through the ANP. It also refers to a more comprehensive methodology that integrates the MCA with SDM to assess urban resilience according to its multidimensionality, complexity and dynamic behaviour over time [17], [18]. However, the illustrated implementation permits determining the usefulness of the ANP to assess urban resilience indicators about urban resilience capacities, following their mutual and multidimensional influences. Experts can thus evaluate how different urban resilience indicators can enrich and maintain urban resilience capacities. Thus, it was also possible to address the importance of recognising these urban resilience capacities in the assessment framework.

Moreover, experts of different disciplines are engaged to assess the proposed assessment framework's usefulness and validity. They also collaborate, giving feedback about the comprehensiveness of the proposed evaluation framework. The result is that through this evaluation, it is possible to operationalise the concept of urban resilience into concrete actions, supporting local stakeholders.

Considering thus the promising perspective of the proposed methodology, the future development of the research will concern the implementation of the obtained final priorities to evaluate the performance of cities in the different urban resilience capacities. The aim is to highlight the strengths and weaknesses of the urban system. Moreover, the performance of urban resilience capacities will be compared with the synthetic index of urban resilience to underline their interdependencies. Moreover, these final priorities will be also be implemented in the SD approach to assess if the defined actions will improve the performance in both urban resilience and urban resilience capacities over time. The final aim of this research is to provide an integrated approach to assess urban resilience within its capacities and operationalise the concept of urban resilience into future urban policies [46], [47], [48].

References

[1] UN-Habitat. Trends in urban resilience. 2017. Epub ahead of print 2017. https://doi.org/10.1007/978-3-319-39812-9
[2] World Economic Forum: Global Risks Report 2019. *Computer Fraud & Security* 2019:2019(2):4 https://doi.org/10.1016/S1361-3723(19)30016-8
[3] da Silva J., Moench M. City Resilience Framework: A holistic evidence-based framework for understanding city resilience *Arup* 2014.
[4] Valdés H. M., *et al.* How to make cities more resilient. Geneva: United Nations, 2012.
[5] Song J., *et al.* Resilience-vulnerability balance to urban flooding: A case study in a densely populated coastal city in China. *Cities* 2019:95:102381. https://doi.org/10.1016/j.cities.2019.06.012
[6] Sharifi A. Urban Resilience Assessment: Mapping Knowledge Structure and Trends. *Sustainability* 2020:12:5918. https://doi.org/10.3390/su12155918
[7] Quinlan A. E. Measuring and assessing resilience: broadening understanding through multiple disciplinary perspectives. *Journal of Applied Ecology* 2016:53:677–687. https://doi.org/10.1111/1365-2664.12550
[8] Shi Y., *et al.* Assessment methods of urban system resilience: From the perspective of complex adaptive system theory. *Cities* 2021:112:103141. https://doi.org/10.1016/j.cities.2021.103141
[9] Moghadas M., *et al.* A multi-criteria approach for assessing urban flood resilience in Tehran, Iran. *International Journal of Disaster Risk Reduction* 2019:35:101069. https://doi.org/10.1016/j.ijdrr.2019.101069
[10] Bridget-Jones S., Bhoite S. City Resilience Index. Canberra: ARUP, 2015.
[11] Fox-Lent C., Bates M., Linkov I. A matrix approach to community resilience assessment: An illustrative case at Rockaway Peninsula. *Environment Systems and Decisions* 2015:35:209–218. https://doi.org/10.1007/s10669-015-9555-4
[12] Sharifi A., Yamagata Y. Urban Resilience Assessment: Multiple Dimensions, Criteria, and Indicators. Urban Resilience. Cham: Springer, 2016:259–276. https://doi.org/10.1007/978-3-319-39812-9_13

[13] Wardekker A., *et al.* A diagnostic tool for supporting policymaking on urban resilience. *Cities* 2020:101:102691. https://doi.org/10.1016/j.cities.2020.102691
[14] Chelleri L., Baravikova A. Understandings of urban resilience meanings and principles across Europe. *Cities* 2021:108:102985. https://doi.org/10.1016/j.cities.2020.102985
[15] Saaty T. L. Theory and Applications of the Analytic Network Process: Decision Making with Benefits, Opportunities, Costs, and Risks. RWS Publications, 2005.
[16] Saaty T. L. Fundamentals of the analytic network process — Dependence and feedback in decision-making with a single network. *Journal of Systems Science and Systems Engineering* 2004:13:129–157. https://doi.org/10.1007/s11518-006-0158-y
[17] Bottero M., Datola G., De Angelis E. A System Dynamics Model and Analytic Network Process: An Integrated Approach to Investigate Urban Resilience. *Land* 2020:9:242. https://doi.org/10.3390/land9080242
[18] Datola G., Bottero M., De Angelis E. How Urban Resilience Can Change Cities: A System Dynamics Model Approach. *Proceedings of the ICCSA 2019: Computational Science and Its Applications* 2019:108–122. https://doi.org/10.1007/978-3-030-24305-0_9
[19] Leichenko R. Climate change and urban resilience. *Current Opinion in Environmental Sustainability* 2011:3:164–168. https://doi.org/10.1016/j.cosust.2010.12.014
[20] Campanella T. Urban Resilience and the Recovery of New Orleans. *Journal of the American Planning Association* 2006:72:141–146. https://doi.org/10.1080/01944360608976734
[21] Meerow S., Newell J. P., Stults M. Defining urban resilience: A review. *Landscape and Urban Planning* 2016:147:38–49. https://doi.org/10.1016/j.landurbplan.2015.11.011
[22] Davoudi S., Brooks E., Mehmood A. Evolutionary Resilience and Strategies for Climate Adaptation. *Planning Practice & Research* 2013:28:307. https://doi.org/10.1080/02697459.2013.787695
[23] Holling C. S. of Ecological Systems. *Annual Review of Ecology and Systematics* 1973:4:1–23. https://doi.org/10.1146/annurev.es.04.110173.000245
[24] Ribeiro P. J. G. Pena Jardim Gonçalves LA. Urban resilience: A conceptual framework. *Sustainable Cities and Society* 2019:50:101625. https://doi.org/10.1016/j.scs.2019.101625
[25] Galderisi A. Urban resilience: A framework for empowering cities in face of heterogeneous risk factors. *Z magazine (Boston, Mass)* 2014:11:36–58.
[26] Bottero M., Datola G., De Angelis E. *Exploring the Redundancy Capacity Through a System Dynamics Approach.Proceedings of the ICCSA 2020: Computational Science and Its Applications* 2020:366–378. https://doi.org/10.1007/978-3-030-58814-4_26
[27] Lu P., Stead D. Understanding the notion of resilience in spatial planning: A case study of Rotterdam, The Netherlands. *Cities* 2013:35:200–212. https://doi.org/10.1016/j.cities.2013.06.001
[28] Wardekker J. A.6 *et al.* Operationalising a resilience approach to adapting an urban delta to uncertain climate changes. *Technological Forecasting and Social Change* 2010:77:987–998. https://doi.org/10.1016/j.techfore.2009.11.005
[29] Kim D., Lim U. Urban Resilience in Climate Change Adaptation: A Conceptual Framework. *Sustainability* 2016:8:405. https://doi.org/10.3390/su8040405
[30] Spaans M., Waterhout B. Building up resilience in cities worldwide – Rotterdam as participant in the 100 Resilient Cities Programme. *Cities* 2017:61:109–116. https://doi.org/10.1016/j.cities.2016.05.011
[31] Godschalk D. R. Urban Hazard Mitigation: Creating Resilient Cities. *Natural Hazards Review* 2003:4:136–143. https://doi.org/10.1061/(ASCE)1527-6988(2003)4:3(136)
[32] Allan P., Bryant M. Resilience as a framework for urbanism and recovery. *Journal of Landscape Architecture* 2011:6:34–45. https://doi.org/10.1080/18626033.2011.9723453
[33] McLellan B., *et al.* Resilience, Sustainability and Risk Management: A Focus on Energy. *Challenges* 2012:3:153–182. https://doi.org/10.3390/challe3020153
[34] Ribeiro P. J. G., Pena Jardim Gonçalves L. A. Urban resilience: A conceptual framework. *Sustainable Cities and Society* 2019:50:101625. https://doi.org/10.1016/j.scs.2019.101625
[35] Meerow S., Stults M. Comparing Conceptualizations of Urban Climate Resilience in Theory and Practice. *Sustainability* 2016:8:701. https://doi.org/10.3390/su8070701
[36] Tyler S., Moench M. A framework for urban climate resilience. *Climate and Development* 2012:4:311–326. https://doi.org/10.1080/17565529.2012.745389
[37] Leichenko R. Climate change and urban resilience. *Current Opinion in Environmental Sustainability* 2011:3:164–168. https://doi.org/10.1016/j.cosust.2010.12.014
[38] Sharifi A., Yamagata Y. Principles and criteria for assessing urban energy resilience: A literature review. *Renewable and Sustainable Energy Reviews* 2016:60:1654–1677. https://doi.org/10.1016/j.rser.2016.03.028
[39] Cutter S. L., Burton C. G., Emrich C. T. Disaster Resilience Indicators for Benchmarking Baseline Conditions. *Journal of Homeland Security and Emergency Management* 2010:7(1):51. https://doi.org/10.2202/1547-7355.1732
[40] Cutter S. L., Ash K. D., Emrich C. T. The geographies of community disaster resilience. *Global Environmental Change* 2014:29:65–77. https://doi.org/10.1016/j.gloenvcha.2014.08.005
[41] Norris F. H., *et al.* Community resilience as a metaphor, theory, set of capacities, and strategy for disaster readiness. *American Journal of Community Psychology* 2008:41:127–150. https://doi.org/10.1007/s10464-007-9156-6

[42] Figueiredo L., Honiden T., Schumann A. Indicators for Resilient Cities. OECD Regional Development Working Papers. Pars: OECD, 2018. https://doi.org/10.1787/6f1f6065-en

[43] Feldmeyer D., *et al.* Indicators for Monitoring Urban Climate Change Resilience and Adaptation. *Sustainability* 2019:11(10):2931. https://doi.org/10.3390/su11102931

[44] Assumma V., *et al.* An Analytic Network Process (ANP)-Based Approach for Investigating Alternative Planning Scenarios of Mining Activities in Piedmont Region. *Lecture Notes in Computer Science* 2020:355–365. https://doi.org/10.1007/978-3-030-58814-4_25

[45] Saaty R. W. The analytic hierarchy process-what it is and how it is used. *Mathematical Modelling* 1987:9(3–5):161–176. https://doi.org/10.1016/0270-0255(87)90473-8

[46] Dell'Ovo M., Oppio A., Capolongo S. Structuring the Decision Problem. A Spatial Multi-methodological Approach. Cham: Springer International Publishing, 2020:29–51. https://doi.org/10.1007/978-3-030-50173-0_2

[47] Caprioli C., Bottero M. Addressing complex challenges in transformations and planning: A fuzzy spatial multicriteria analysis for identifying suitable locations for urban infrastructures. *Land Use Policy* 2021:102:105147. https://doi.org/10.1016/j.landusepol.2020.105147

[48] Becchio C., Bottero M. C., Corgnati S. P., Dell'Anna F. Evaluating Health Benefits of Urban Energy Retrofitting: An Application for the City of Turin. In: Bisello A., Vettorato D., Laconte P., Costa S. (eds) *Smart and Sustainable Planning for Cities and Regions*. SSPCR 2017. Green Energy and Technology. Springer, Cham. https://doi.org/10.1007/978-3-319-75774-2_20