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Multiple-Criteria Decision Analysis of Urban Planning Methods towards Resilient Open Urban Spaces

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1 ABSTRACT

Cities are dynamic systems that need to plan for development with resilience, while facing an increasing set of multidimensional challenges and emerging operating trends (e.g. Smart Cities) (Schmitt, 2015). In the framework of new Urban Strategies (Digital Europe Program, 2021-2027; Green Deal, 2019), local authorities play a key role in making the right decisions for covering current and future needs.

Public/outdoor urban spaces are vital parts of cities as they define citizens' quality of life and the ability of cities to respond to urban challenges. In this context, this research aims to support the decision-making process for shaping, designing and managing public/outdoor urban spaces by using measurable and multicriteria indicators to evaluate alternative climate-sensitive design and regeneration plans of urban areas within risk and uncertainty.

Emphasis is placed on both supply and demand for outdoor urban areas. Demand is studied by disaggregate analysis for identifying citizens' needs through questionnaire survey. Supply side is placed at the center of the research by developing a multiple-criteria assessment methodology of urban planning methods. The main evaluation criteria involve the bioclimatic impact of the studied methods, the air pollution detected in microclimate as well as financial cost for their implementation and operation.

In particular, questionnaires' results revealed that citizens prefer open spaces as they provide a feeling of freedom and the chance to be closer to nature. Based on these, citizens visit open spaces with green areas, incoorporating nature based solutions, as well as places that support walkability and green mobility. In addition, simulation and cost assessment results regarding the studied methods showed the planning solutions involving medium size plants and greenery are low cost interventions, creating favorable microclimate conditions and leading to medium CO_2 concentration.

The benefit of the current research is in the innovative, interdisciplinary and holistic approach of a complex real-word problem combining different research areas, such as environmental science, bioclimatic urban planning and decision-making process. The multiple-criteria analysis of urban plans leads to a model of the decision-making process on open urban spaces to enhance citizens' quality of life and to ensure urban resilience as well as cities' operational and sustainable future.

Keywords: decision-making process, urban planning methods, multicriteria analysis, resilience, open urban spaces

2 INTRODUCTION

As Batty (2008) argues, cities are complex, dynamic systems, which are constantly growing from the unstoppable desire for space. As the phenomenon of urbanization is becoming increasingly intense but also complicated, the attempt to become managing is continuous and is often expressed through the development of urban models. With half of the world's population living in urban areas (WHO, 2014), addressing and mitigating the impact of phenomena that are associated withclimate change on urban processes is critical. The future of urban areas can bedesigned based on a dynamic system framework, including global relations, localpowers and emerging trends and needs in cities, e.g. smart cities (Schmitt, 2015). Identification of urban planning needs are key to improving the effectiveness ofconstruction and management policies in urban areas and require quick and riskaverse decisions, the results of which can only be evident in the future (Chondrogianni & Stephanedes; 2021).

The concept of urbam public space is multifaceted and complex and its problematic has been the subject of study among many disciplines such as economy, sociology, politics and spatial planning. These sectors perceive and approach the concept of public space differently, and at the same time, they all complement each other for a better understanding of the complex concept (Osmidopoulou, 2019). It is therefore evident that the public urban space is a complex concept with multiple meanings, utilities and definitions while an essential component of the structure, organization and design of cities. Open public space plays a decisive role in shaping a city while being called upon to form urban fabric by giving life, diversity and meaning to it. Resilient cities target implementing regeneration plans for their open public spaces that are manageable and shaped with main objective the maximization of cities' benefits in terms of economic and environmental impact, sustainability and resilience (Chondrogianni & Stephanedes; 2021).

In this framework, the main objective of this research is to propose a multiple-criteria decision analysis of urban planning methods in order to suppoer the involved stakeholders in creating and providing resilient open urban spaces, in which a range of developing risks could be managed, and new challenges could be met city. To achieve it as case study area of an open urban space was selected and a multiple-criteria assessment methodology for pontential urban planning interventions was developped.

3 MATERIALS AND METHODS

Recognizing the needs and desires of users in the study area was attempted by drawing up a suitable questionnaire. This chapter describes the method used to collect data on users' needs. Initially, the reasons that have prompted us to choose the use of questionnaires to identify users' needs and the collection of demand data for urban outdoor spaces and the study area specifically.

Following the user needs‘ identification, the development of alternative regeneration scenarios incorporating the desired set of methods and guidelines of bioclimatic urban design of open urban spaces is decided. For the analysis and evaluation of the urban planning methods, the microclimate of the scenarios is simulated using ENVI-met model and software. The model allows simulating the microclimate of an area so that the effects of urban design are measurable and comparable. For visualization and analysis of simulations results, Leonardo software is used.

Added to the microclimate simulations, the financial cost of each urban method was estimated too. Cost is a defining parameter in the multiple-criteria decision analysis and the identification of the general construction and maintenance cost was of high priority in this research.

Regarding the case study area, the open space of Patras Old Port in Greece has been selected. The urban space of Old Port is the main connecting area between city and sea but remains degraded as its complex design has been debated over several years (Architectural Competition "Rehabilitation of Old Port of Patra", 2016). This outdoor space was considered suitable for the development of regeneration scenarios and the microclimate simulations as it is a "blank" space without altitude variations, free in perimeter from urban structures which can act as a base ("white canvas") for experimentation. In this area of Mediterranean climate high humidity conditions are stable owing to the extended water element.

3.1 User needs' identification process

To identify user needs and preferences, one of the usual research methods is the use of a questionnaire which is supplemented by research subjects. The questionnaire is a research medium made up of a series of questions and is the means of communication between the researcher and the respondents, in a direct or indirect way, depending on the method of data collection. One of the most important factors in any research is the design of the real questionnaire. The questions and instructions should be easy to understand and follow. The design of the questionnaire took into account the basic principles as recorded by Javeau to serve the needs of the research and to ensure the validity of the results (Javeau, 2000).

For analysing the demand side in the urban spaces, a set of questionshas been developed; 150 citizens responded by identifying the places they visit the most and the reasons for their preference, their main inefficiences and their impact on citizens' daily life.

3.2 Urban regeneration scenarios in case study area

The developed regeneration scenarios aim to incorporate the urban planning methods and guidelines for supporting users‘ preferrences as identified through the questionnaires and achieving thermal and air comfort conditions in open spaces as well as limited CO_2 concentration, identified through literature review. Based on these data and references, the studied methods can be included in three general categories: Vegetation, Geometric structure, Material (Chondrogianni & Stephanedes; 2021).

In the first scenario, small interventions, from the categories of geometric structure and vegetation were selected based on the current situation and the existing materials. As it is presented in the masterplan (Fig. 1) indicates the interventions, Tree canopy with big trees (M1) and Green Fences with medium vegetation (M2) or larger trees (M4) for wind protection have been seleced.

Figure 1: Masterplan of Scenario 1

In Scenario 2, the vegetation and geometric structures of the open space remain the same as in Scenario1. The proposed interventions focus on the construction and coating materials, as it is shown in the masterplan of Figure 2. The material have been selected based on their main characteristics and their ability to create more favorable microclimate conditions, and mitigate climate change phenomena, such as the urban heat island. For example, M5 indicates the use of medium vegetation combined with brick/cobblestone pavement, M10 refers to the use of white concrete as pavement while covering a surface with water is represented in M8.

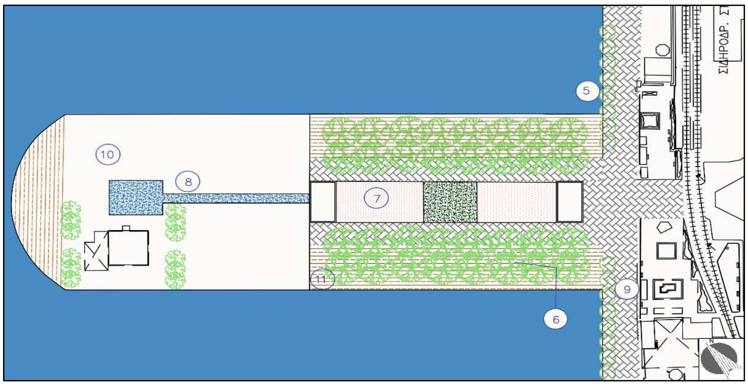

Figure 2: Masterplan of Scenario 2

In Scenario 3, more complex planning solutions have been developped with interventions that combine methods from the three categories. For example, the masterplan (Fig. 3) illustrates the use of medium palm trees over wooden pavement (M13), the creation of a Public Passage between buildings with a green roof, and a pavilion with facades (M17) or the design of a Closed Plateau (M18) combining the use of geometric structures, vegetation and materials (brick/cobblestone) for wind protection and thermal comfort.

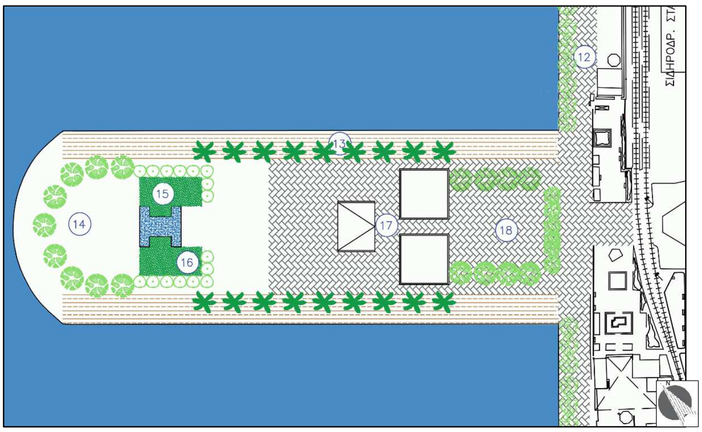

Figure 3: Masterplan of Scenario 3

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The planning methods, implemented in the three scenarios and indicated with numbers 1-18 in Figures 1-3 are summarized and described in Table 1 as M1-M18 with their main characteristics (e.g., name, category, height, albedo). Through this recording, added urban structures/vegetation/materials with common/similar characteristics as those designed in the masterplans and analyzed in the microclimate simulations can be comparatively evaluated.

Code	M1	M2	M3	M4	M5	M6
Name	Tree Canopy	Medium Vegetation	Open square-Concrete	Green fence	Medium Vegetation II	Tree Canopy II
Category	Vegetation	Vegetation	Geometric structure/ Material	Vegetation	Vegetation/ Material	Vegetation/ Material
Height	9m	2m	9m	5m	2m	9m
Aperture diameter	9m	2m	-	4m	2m	9m
Sheet type-LAD	Deciduous, oval leaves	Dense vegetation	-	Deciduous, low LAD	Dense vegetation	Deciduous, oval leaves
Construction material	-	-	-	-	Brick/ cobblestone pavement	Wooden pavement
Albedo	-	-	0.3	-	0.5	0.8
Orientation	N-S	NW	-	NW-SE	NE	N-S
Green roof-facade	-	-	-	-	-	-
Code	**M7**	**M8**	**M9**	**M10**	**M11**	**M12**
Name	Square II-Terre battue	Water surface	Brick / cobblestone pavement	White concrete pavement	Wooden pavement	Green Fence II
Category	Geometric structure/ Material	Material	Material	Material	Material	Vegetation/ Material
Height	9m	0.5m	-	-	-	7m
Aperture diameter	-	10m	-	-	-	5m
Sheet type-LAD	-		-	-	-	Deciduous, low LAD
Construction material	-	Water	-	-	-	Brick/ cobblestone pavement
Albedo	0.8	-	0.5	0.8	0.8	0.5
Orientation	-	-	-	-	-	NW
Green roof-facade	-	-	-	-	-	-
Code	**M13**	**M14**	**M15**	**M16**	**M17**	**M18**
Name	Tree planting	Tree planting II	Low Vegetation	Water Surface-Fountain	Public Passage	Closed Plateau
Category	Vegetation/ Material	Vegetation/ Material	Vegetation	Material	Geometric structure/Vegetation	Geometric structure/ Material/Vegetation
Height	5m	5-7m	0.2-2m	2m	3-9m	5-9m
Aperture diameter	5m	5m	2m	10m	6m	30-40m
Sheet type-LAD	Medium palm tree, medium LAD	Deciduous, high LAD	Dense	-	-	Deciduous, low LAD
Construction material	Wooden pavement	White concrete pavement	-	-	Metal &concrete	Brick/ cobblestone pavement
Albedo	0.8	0.8	-	-	0.5-0.8	0.5
Orientation	N-S	-	-	-	NW-SE	N-S-E-W
Green roof-facade	-	-	-	-	Green roof & green wall	-

Table 1: Methods and characteristics of bioclimatic urban planning

3.3 Microclimate simulations of urban planning scenarios

In this research, it is decided the use of simulations, for evaluating the three basic regeneration scenarios of the study area, by ENVI-met across all year seasons, taking into considearation that microclimate and air pollution conditions created by urban planning methods in open spaces differ significally over the seasons. More specifically, one day of extreme weather conditions in winter and one in summer were simulated, as well as 24 hours of medium prevailing conditions in spring and in autumn. The duration of each microclimate simulation was 24 hours, and the time interval of each simulation was 1 hour.

The most extreme values of air temperature (oC), wind speed (m/s), wind direction and relative humidity (%) recorded in winter and summer of 2019 for the case study were input to the microclimate simulations

(AccuWeather, 2019; Chondrogianni & Stephanedes; 2021). Added to the extreme weather conditions, two more microclimate cases for each regeneration scenario were defined and simulated. In these cases, the average prevailing air temperature (min-max), the average wind speed and direction, and the average relative humidity (%) recorded in Patras during spring and autumn were the simulation inputs (AccuWeather, 2019; Chondrogianni & Stephanedes; 2021). The exact values of microclimate parameters used in the research simulations are presented by season in Table 2.

Season	**Low temperature (°C)**	**High temperature (°C)**	**Wind speed (m/s)**	**Wind direction**	**Relative humidity (%)**
Winter	-2	8	4.8	NE	57
Summer	25	38	4.3	SE	65
Spring	19	26	4.4	SW	55
Autumn	13	19	4.1	NE	62

Table 2: Microclimate input values to the simulation models by season

3.4 Financial cost estimation

Following the evaluation of the various methods of designing outdoor urban spaces for their contribution to urban durability, through the microclimate simulations, it is crucial to assess the financial costs of each one as the cost-profit analysis is a widely used method to support the decision -making process in urban regeneraion plans (Tudela et al., 2006).

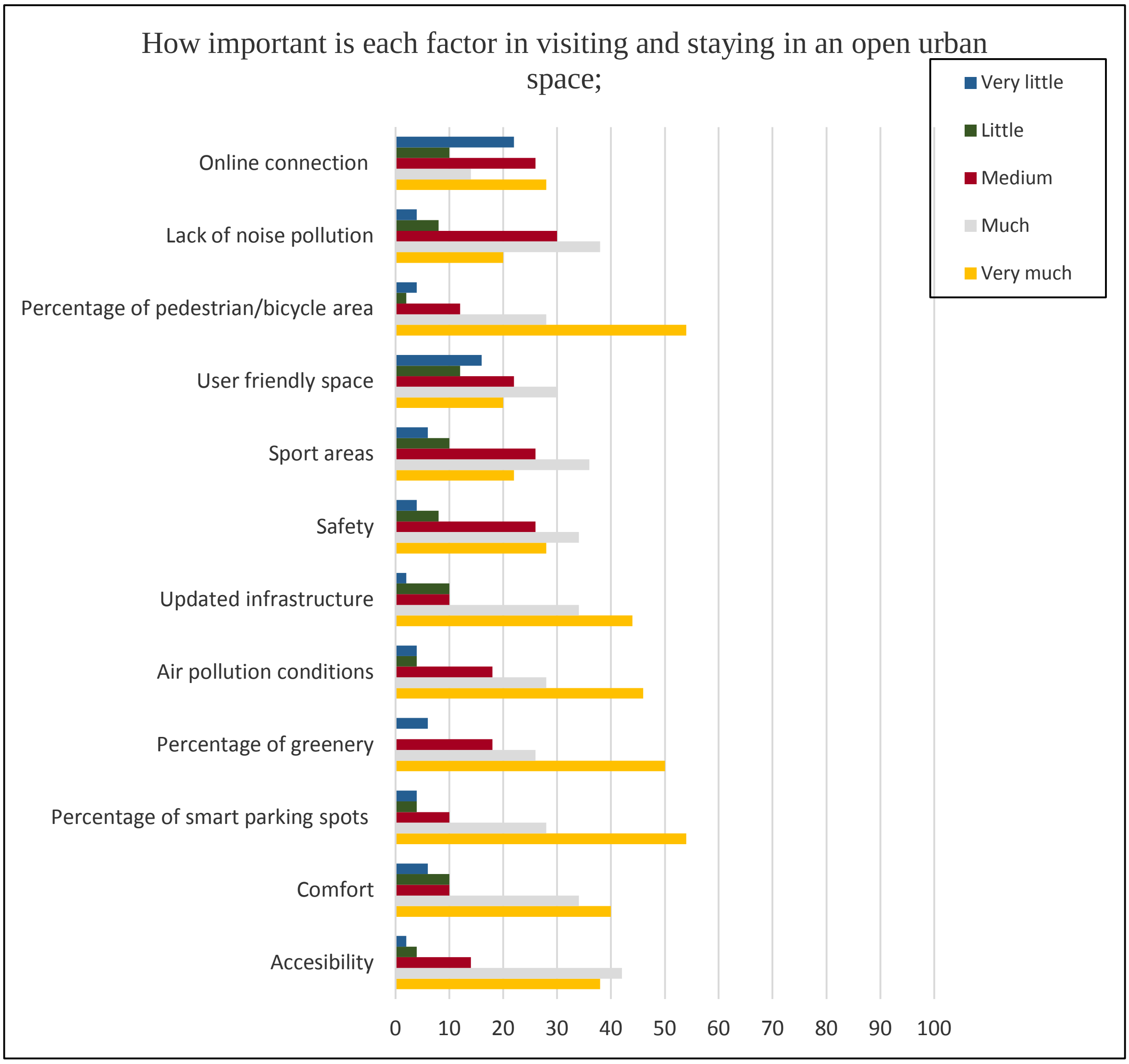

Figure 4. User preferences on public spaces

It is therefore necessary to note that the choice of an urban intervention is based on both the existence of the financial resources required for construction and for the maintenance of the intervention for the future so that the public benefits of the regeneration process of an outdoor urban space to be ensured.The main objective of the processes is to create public spaces for the citizens, with a pleasant microclimate and reduced air pollution conditions that can be constructed economically and be maintained effectively as the results of users needs‘ questionnaiers revealed.

CO_2 Concentration						Bioclimatic Index
M1- Tree canopy						
	Winter	Spring	Autumn	Summer		
AV.	404,64	403,48	402,72	407,25	404,53	0.66
M2- Medium Vegetation						
	Winter	Spring	Autumn	Summer		
AV.	404,64	402,04	403,02	407,75	404,36	1
M3- Open square-Concrete						
	Winter	Spring	Autumn	Summer		
AV.	404,60	402,75	402,74	407,06	404,29	0.69
M4 -Green fence						
	Winter	Spring	Autumn	Summer		
AV.	404,62	403,65	402,91	407,46	404,66	0.85
M5- Medium Vegetation II						
	Winter	Spring	Autumn	Summer		
AV.	404,74	403,58	403,15	407,53	404,75	0.93
M6-Tree canopy II						
	Winter	Spring	Autumn	Summer		
AV.	404,55	403,39	402,74	406,39	404,27	0.41
M7- Terre battue pavement						
	Winter	Spring	Autumn	Summer		
AV.	404,56	403,55	402,89	406,90	404,47	0.71
M8- Water surface						
	Winter	Spring	Autumn	Summer		
AV.	404,51	403,15	402,69	406,27	404,15	0.53
M9- Brick/cobblestone pavement						
	Winter	Spring	Autumn	Summer		
AV.	404,88	403,84	402,86	407,61	404,77	0.81
M10- White concrete pavement						
	Winter	Spring	Autumn	Summer		
AV.	404,51	403,42	402,74	405,99	404,17	0.48
M11- Wooden pavement						
	Winter	Spring	Autumn	Summer		
AV.	404,88	403,84	402,86	407,61	404,77	0.39
M12- Green Fence II						
	Winter	Spring	Autumn	Summer		
AV.	404,67	404,54	402,99	407,44	404,91	0.59
M13- Tree planting						
	Winter	Spring	Autumn	Summer		
AV.	404,49	403,79	402,52	406,96	404,44	0.88
M14- Tree planting II						
	Winter	Spring	Autumn	Summer		
AV.	404,33	402,92	402,48	391,82	400,39	0.76
M15- Low vegetation						
	Winter	Spring	Autumn	Summer		
AV.	400,36	389,35	402,18	400,36	398,06	0.34
M16- Water Surface II-Fountain						
	Winter	Spring	Autumn	Summer		
AV.	399,94	402,72	397,74	406,27	401,67	0.45
M17- Public Passage						
	Winter	Spring	Autumn	Summer		
AV.	404,57	404,15	402,75	407,64	404,78	0.62
M18- Closed Plateau						
	Winter	Spring	Autumn	Summer		
AV.	404,59	403,74	402,79	407,60	404,68	0.57

Table 3: CO_2 concentration in the microclimate and Bioclimatic Index of the urban planning methods

4 RESULTS AND DISCUSSION

4.1 Users’ preferences and needs

From the questionnaires’ results, the most important are referring to the factors that define citizens’ choice to visit an urban public space. The Figure 4 shows the results regarding this parameter. The factors that affect the choice and preference of users to visit and remain in an outdoor urban area are mainly the greenery rate, the percentage of sidewalks/bike lanes and the quality of the air they inhale. In addition, users seem to be interested in accessibility, mobility and the level of safety in these areas. Finally, about half of the respondents want to access the internet and have electrically interconnected infrastructure.

4.2 Bioclimatic Index and CO_2 concentration results

The evaluation of the urban planning methods regarding the thermal and air comfort has been analyzed and presented in previous research concluding that medium size vegetation combined with natural coating materials create the most favorable microclimate conditions in seaside Mediterranean urban spaces (Chondrogianni & Stephanedes, 2021).

In addition, the CO_2 concentration in the microclimate of urban methods has been analyzed in previous research (Chondrogianni & Stephanedes, 2022) and showed that the method of low vegetation, including shrubs and grasslands as well as the water surface II-fountain (M15, M16) operate significantly more beneficial to reducing CO_2 concentration in microclimate, and therefore contributing more effectively in urban resilience to climate change. In the opposite, the public passage (M17) and green fence II (M12) lead to larger values of CO_2 concentration in the urban microclimate. In these methods, the lack of intense wind movement and circulation due to the narrow passage between the building in M17, combined with the dense green structure of M12, providing to wind protection, lead to higher CO_2 concentrations in the level of the pedestrians (+1.7m).

The microclimate simulation results are presented briefly in Table 3.

4.3 Financial cost results

The financial cost is estimated through the cost of construction for the minimum quantity and maintenance cost of each intervention for one year. For example, the cost fot the method M1-Tree canopy is calculated in detail in Table 4.

M1-Tree canopy					
		Unit cost	Ελάχιστη Ποσότητα	Σύνολο	Συν. Κόστος (€)
	Construction cost/tree	1000€/tree	6	6000	7392
	Labor cost	30€/hour	40	1200	
	Maintenance cost /year	32€/tree	6	192	

Table 4: Financial cost of the urban planning methods

The total costs per method are presented briefly in Table 5.

Code	Urban Planning Method	Cost per method (€) (Construction and annual cost)
M1	Tree canopy	7392
M2	Medium Vegetation	1030
M3	Open square-Concrete	1380
M4	Green fence	3040
M5	Medium Vegetation II	2310
M6	Tree canopy II	10942
M7	Terre battue pavement	4500
M8	Water surface	6970
M9	Brick/cobblestone pavement	1260
M10	White concrete pavement	1515
M11	Wooden pavement	3550
M12	Green Fence II	3600
M13	Tree planting	6590
M14	Tree planting II	4555
M15	Low vegetation	1830
M16	Water Surface II-Fountain	10190
M17	Public Passage	6600/11440
M18	Closed Plateau	5660

Table 5: Financial cost of the urban planning methods

include planting with high and large trees and their cost for placement is significantly higher than smaller trees. In addition, high costs are found in the construction of a green roof or green wall in M17-public passage, as they require special water supply systems and vegetation support on buildings, as well as the construction and maintenance of fountain (M16-Water Surface II-Fountain). The most economical interventions are M2-Medium Vegetation and M9- Brick/cobblestone pavement. In general, interventions related to soil coating either with some material or water, with the exception of the Terre battue pavement

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(M7) can be selected for a small area as they are more economical while low and medium vegetation interventions are the least costly (M5- Medium Vegetation II, M15- Low vegetation).

5 CONCLUSIONS

Evaluating and implementing planning solutions for public urban spaces is a complex process that is best supported by a multiparameter approach that supports decision makers on selecting and implementing masterplans that have a positive impact in urban resilience and citizens' quality of life.

This research focused on the standardization, classification and multi-criteria analysis of urban planning solutions, commonly proposed for designing bioclimatic open spaces and improving urban microclimate and resilience. Their asssessment involved their contribution in thermal comfort, reducing air pollution, specific CO2 concentration, and their financial cost for construction and maintenance.

Further research should work on the extendibility and transferability properties of the research results through the identification and evaluation of additional types of urban planning methods in multiple locations across Europe with different climate conditions. Finally, more classes of planning scenarios could be simulated and rated, across a wider range of criteria and parameters.

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