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Nature-Based Solutions: Thermal Comfort Improvement and Psychological Wellbeing, a Case Study in Genoa, Italy

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Abstract: The urban heat island (UHI) effect is among the most critical issues caused by human activities and high building density. UHI has severe impacts on the urban and natural environment as well as on human health and wellbeing. The research presented here aims at evaluating the effects of nature-based solutions (NBS) in improving the livability of a district in the city of Genoa, which is heavily cemented and a major example of the heat island phenomenon. This study focuses on the microclimatic benefits of urban heat island mitigation as well as on psychological and perceptual aspects. A preliminary analysis of the district through CFD simulations using Envi-met software allowed for selection of the most suitable areas for a system of punctual interventions in urban regeneration using nature-based solutions. For each area identified, we simulated the effects of different design scenarios on microclimate mitigation and thermal comfort improvement. In addition, to evaluate the perceptual benefits of the most well-performing design scenarios, we set up a web-based survey that was administered to a convenience sample of Genoa residents. In terms of aesthetic satisfaction and perception of improved conditions of physical and psychological well-being, the preferred design outcomes were those which emphasized a freer and more natural environment. This study shows that nature-based solutions can improve the overall conditions of dense urban areas; microclimate performance and psychological effects should be both considered in the design process in order to improve the wellbeing of urban citizens.

Keywords: nature-based solutions; urban heat island (UHI); human wellbeing; thermal comfort; urban regeneration; citizens' perception

Citation: Mosca, F.; Dotti Sani, G.M.; Giachetta, A.; Perini, K. Nature-Based Solutions: Thermal Comfort Improvement and Psychological Wellbeing, a Case Study in Genoa, Italy. *Sustainability* **2021**, *13*, 11638. https://doi.org/10.3390/su132111638

Academic Editors: Agnese Salvati, Gianpiero Evola, Massimo Palme and Giacomo Chiesa

Received: 30 September 2021
Accepted: 18 October 2021
Published: 21 October 2021

1. Introduction

Rapid urbanization, anthropic activities and land use changes (artificial vs. vegetated and natural areas) affect the quality of life of citizens [1,2]. Among all the consequences, the 'urban heat island' (UHI) is one of the most relevant [3]. This phenomenon occurs particularly during the summer, due to many artificial surfaces with a very low albedo [4], as well as road traffic, industrial activities, and conditioning [5,6], but also due to the increase in the Bowen ratio, i.e., the gap between the flow of sensible heat and the latent flow [7].

Related consequences of urbanization include water management and runoff, air quality, ecosystem balance, and biodiversity [8,9]. Poor environmental quality can also cause different kinds of pathological conditions that involve public health for citizens [10–12], occurring especially in weaker categories of citizens such as the elderly [10].

Regenerative design aims at finding solutions to mitigate such negative effects [13]; these solutions can be nature-based and may or may not include artificial materials. Concerning nature-based solutions, these are now widely studied and prove that the integration of green areas in urban environment can be effective at different scales according to needs, availability, and opportunities. Integrating plants in an urban context as a tool for urban regeneration can be based on more traditional solutions, such as the planting of trees, the introduction of areas with grass and flowerbeds with hedges and turf [14–16], and the use of solutions which include artificial materials for performance optimization. Among these solutions, different kinds of extensive, light intensive, or heavy intensive types of green roofs can be mentioned; such systems provide microclimatic benefits along with water regulation [17–19] and energy performance improvements [20–23]. Secondly, green façades with possible application through direct or simple indirect greening systems, such as planter boxes or living wall systems [24–26], can locally reduce the surface temperatures where they are applied, and consequently have an influence on relative humidity, ultimately improving local comfort [27–29].

The mentioned nature-based solutions can limit the effects of the progressive exclusion of vegetation in cities [30]. Lack of greening not only has environmental and ecological consequences but may also have social and psychological consequences on city dwellers, who turn out to be less and less connected with nature [31].

Bringing people closer to nature and its elements enables them to take advantage of a wide range of benefits and connect with it again, supporting the natural tension towards what is vital [32,33].

Therefore, the integration of nature-based solutions in highly built-up contexts can mitigate both environmental and ecological issues caused by human activities and climate change, such as surface runoff [32,33], the heat island phenomenon [34], air pollution [35] and loss of biodiversity [36,37], while also influencing the social conditions of these areas and contributing to the improvement of microclimatic conditions and the psychological well-being of citizen [1,15,36].

Research on the benefits of vegetation to date has mainly focused on aspects of regulation ecosystem services concerning physical conditions [7,38] or on aspects of psychological comfort improvement [1]. This study aims to simultaneously investigate both issues, particularly in relation to the design process of urban regeneration, and to relate them to assess the points of contact between objective and subjective benefits.

Therefore, the main objective is to define the relation between the physical and psychological benefits of nature-based solutions (NBS), in particular, microclimatic benefits in relation to thermal comfort [7,39,40] and perceptual benefits [41–45]. This is because the improvement of peoples' well-being is linked to both areas.

To do this, we aim to identify possible combinations of nature-based solutions with enhancing effects both in terms of improving microclimate comfort and psychological comfort for the potential users of the retrained areas.

In brief, the main goals of the research are:

- To define which combinations of NBS work better in terms of thermal comfort improvement and local UHI mitigation.
- To evaluate the influence of urban morphonology and environmental conditions on NBS microclimatic performances.
- To evaluate how microclimatic and psychological and social aspects can be part of the urban design process, by a) assessing the value attributed by citizens to the presence of green spaces in cities and in highly built-up environments in terms of their ability to improve mood and well-being, and b) understanding which kind of design solutions with vegetation are most preferred by citizens in relation to the improvement of their quality of life.

2. Methodology

To study both the microclimatic and perceptual effects of nature-based solutions in the urban environment, a case study was identified within the Municipality of Genoa.

The case study was selected within the Climactions project—Adaptation to and Mitigation of Climate Change—Urban Interventions for Health Promotion [46], funded by Comitato Collaborazione Medica (CCM). This project involves the main Italian cities and promotes design intervention using nature-based solutions in densely built-up contexts, in order to mitigate the negative effects of climate change on human health.

The research was developed in three phases (Figure 1):

1. Selecting suitable sites and relative analysis of the microclimatic conditions at the current state.
2. Assessing NBS performances for the selected sites in terms of microclimate regulation and UHI mitigation, drafting of design scenarios and analyzing of thermal comfort.
3. Carrying out a web survey to assess the preferences of citizens regarding the different scenarios and the perceptual and psychological benefits they may favor.

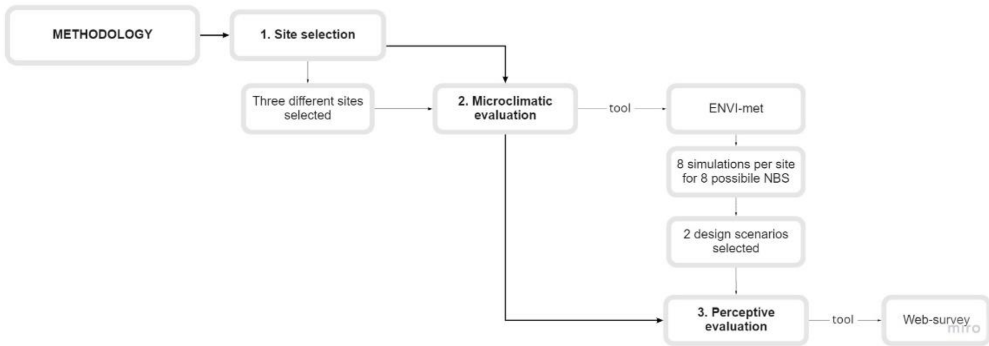

Figure 1. Methodology structure.

To effectively correlate the environmental aspects of NBS with the psychological and social ones, the assessment of well-being improvement was addressed by keeping the variable related to microclimatic control performance fixed (through the formulation of different design scenarios with the same output) and analyzing the variation of the parameter related to the improvement of subjective psychological wellbeing.

2.1. Site Selection

Site selection was based on a literature review, onsite surveys, and simulations of microclimatic conditions. Morabito et al. [47] mapped the main Italian cities, with HERI (Heat-related Elderly Risk Index) distribution highlighted for the summer period (from May till September). In addition, thanks to collaboration with the Municipality of Genoa, specific suitable areas were identified within the district of Cornigliano, an area with a very high risk index related to heatwaves [47] and well known by citizens for the poor quality of public spaces and lack of maintenance, as confirmed by onsite surveys. The coexistence of all the criticalities mentioned above confirmed the need to select some specific urban regeneration interventions not only to improve the microclimatic conditions of the area but also local livability (Figure 2).

Site selection was supported by a preliminary analysis of climatic conditions during the summer period of the year 2020, in order to identify the days with the greatest criticality from the point of view of thermal comfort, and to proceed with the computational fluid dynamics (CFD) simulations using Envi-met Science software (Version 4.4.5). Reference was made to the data on the Ministry of Health portal [48] regarding the days with heatwave alerts issued for the Municipality of Genoa, which allowed identifying the day of 1 August 2020 as particularly critical, with air temperature peaks of 32 °C. This analysis was mainly carried out in order to check the conditions of the pre-selected areas and to define the most critical areas from a thermal comfort point of view.

Figure 2. Orthophoto of the area of Genova Cornigliano.

For the simulations, a suitable area was identified considering all the relevant natural and artificial elements (e.g., railways, waterways and green areas). This choice was conditioned by the fact that the software processes output data and relative maps based on all the main microclimatic parameters (air temperature, relative humidity, wind speed, and direction, mean radiant temperature), but also on the physical (e.g., urban morphology) and geographical characteristics of the site. Simulations were run on a 24-h range in relation to the day of 1 August 2020. All the climatic data in relation to the defined date used for the simulations were taken from the local ARPAL web database (Regional Environmental Protection Agency). In particular, the main parameters considered for the simulations were air temperature, wind direction, wind speed and relative humidity (RH), Figure 3, Table 1).

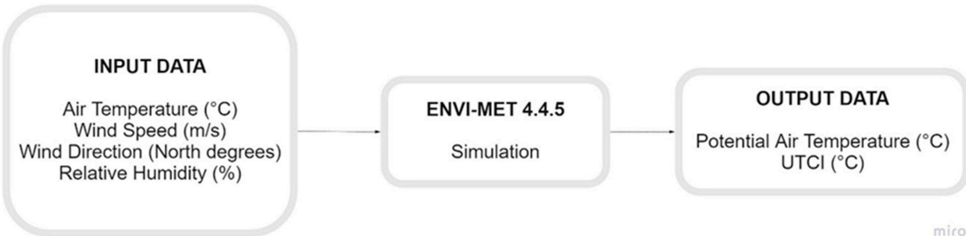

Figure 3. Data used for the CFD simulations with Envi-met Science (Version 4.4.5).

Table 1. Input data for simulations: August (hot summer day), June (standard summer day) and January (standard winter day).

	Max	**Min**	**Mean**
01/08/2020			
Air Temperature (°C)	32.00 (4 P.M.)	25.50 (4 A.M.)	
Relative Humidity (%)			
Main Wind Direction (°)	100 (12 P.M.)	50 (11 P.M.)	135
Medium Wind Speed at 10 m height (m/s)			2.90
19/06/2020			
Air Temperature (°C)	24.10 (4 P.M.)	19.40 (11 P.M.)	
Relative Humidity (%)			
Main Wind Direction (°)	88 (11 P.M.)	70 (5 P.M.)	135
Medium Wind Speed at 10 m height (m/s)			4.50

Table 1. *Cont.*

	Max	Min	Mean
22/01/2020			
Air Temperature (°C)	17.50 (2 P.M.)	7.60 (1 A.M.)	
Relative Humidity (%)			
Main Wind Direction (°)	69 (11 P.M.)	30 (8 A.M.)	90
Medium Wind Speed at 10 m height (m/s)			9.20

The site selection phase and preliminary simulations allowed identification of three sites within the selected macro area (Genoa Cornigliano), named "Site A, B, and C", in which the improvement of microclimatic and psychological comfort has been assessed through the formulation of project scenarios.

2.2. Thermal Comfort and Microclimate

The second phase of the study aimed at defining possible design strategies for urban regeneration with nature-based solutions for the selected sites.

The possible solutions identified were paving with a high albedo, grass, trees, green façades, shrubs, water mirrors, green roofs, and shelters with climbing plants (Figure 4).

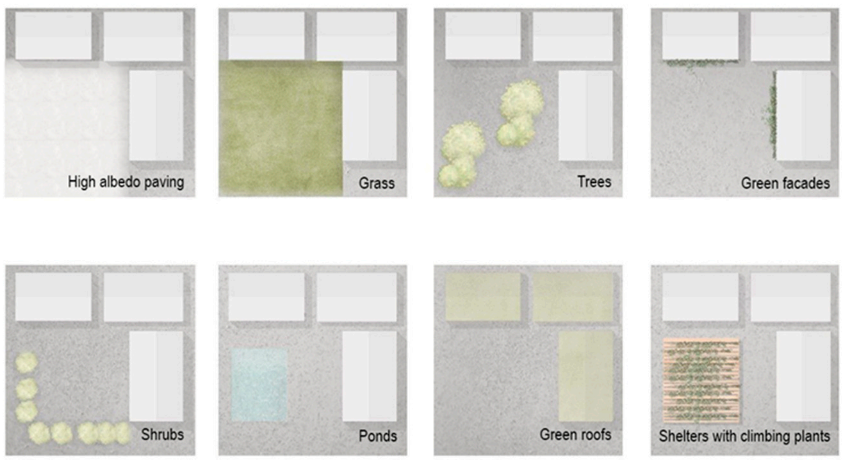

Figure 4. Collection of NBS selected for the three sites of the case study.

NBS were located in the three sites according to building morphology and considering the space available to ensure the correct development of the plants (trees and shrubs) and the creation of shaded areas for citizens.

Eight simulations with ENVI-met allowed quantification of the microclimatic benefits of all the possible solutions for each site, and comparison of the results for the selection of the most efficient configurations.

Several researchers have shown that CFD software can simulate the microclimatic conditions of a specific site by modelling different urban elements such as buildings and vegetation [49]. It is worth specifying that for all the simulations we used the same climatic data in order to allow a comparison with the current, non-green situation. Following analysis of the results, the proposed nature-based solutions were combined with each other to obtain two very different design scenarios for each site that had a similar performance in terms of increasing the level of thermal comfort.

Since all of the simulations launched up to this stage were always carried out concerning the most critical thermal conditions which the city went through in the year 2020, other simulations were also carried out in two other periods characterized by different climatic conditions in order to verify the effectiveness of NBS; i.e., in June 2020 for the summer, to compare the maximum level of thermal stress with the level in more ordinary summer conditions, and in January 2020, to verify that the design made for the summer comfort improvement did not cause thermal discomfort during winter. We focused initially on summer conditions, due to the high risk of heat waves in the area [47]. At the same time, the site within the Municipality of Genoa (Liguria) is in Mediterranean area, and does not present great criticality in the winter period.

Concerning the design configurations, even if the CFD simulation results considerably limited the range of solutions to be adopted, an attempt was still made to vary as much as possible the arrangement of the elements according to the peculiarities of each site. The scenarios were conceived in order to offer residents and users not only the same conditions of thermal comfort as highlighted above, but also the same services (e.g., number of parking spaces) and the same ratios between road and pedestrian areas (more/less green); this peculiarity was imposed to avoid imbalance between the two scenarios.

2.3. Evaluation of Perceptive Benefits

Finally, in the third part of the research, an online survey was carried out to evaluate individual preferences toward the different NBS design scenarios. This survey was administered using social network platforms to a convenience sample of citizens living in the nine Municipalities of Genoa. In particular, numerous neighborhood associations on Facebook were involved, with the aim of delivering the questionnaire to citizens residing in different municipalities within the City of Genoa. Overall, the fieldwork led to the collection of 859 interviews in 14 days of administration (8/02/2021–22/02/2021). Because the survey was carried out during the COVID-19 pandemic, it was not possible to conduct the interviews face-to-face and, as most surveys were carried out entirely online during the pandemic, the final sample is not representative of the population. Nonetheless, it represents a novel and unique tool to gain preliminary insights on the evaluation of individual preferences toward the different NBS design scenarios.

To assess the subjective benefits that vegetation can have on potential users and evaluate subjective preferences regarding the alternative design proposals for the three intervention sites, the survey covered various topics, including basic socio-demographic information on the interviewees, attitudes towards the benefits of natural elements on human life, opinions about use of vegetation in the urban environment, and evaluation of possible NBS project scenarios for urban areas. For this study, we restricted the focus to two main dependent variables. The first gauged the subjective benefits of urban green areas by asking: “When walking in the city center/green areas your mood improves”. Possible answers range from 1, “Completely disagree” to 5, “Completely agree”. The second main dependent variable captured the respondents’ preferences across the different project scenarios. Preferences were assessed using three different items, the exact wording of which is presented in Table 2.

Table 2. List of items for design scenarios evaluation and relative answers.

Questions	Possible Answers		N
Which of the following two urban regeneration project scenarios for the same place do you prefer?	Scenario A	Scenario B	612
Which of the two scenarios do you think would offer you the greatest psychophysical benefit?	Scenario C	Scenario D	724
If you could have a shaded gathering space near your house where you could spend time in summer, which of the following two scenarios would you prefer?	Scenario E	Scenario F	718

To achieve the two main objectives described above, we first explored whether the subjects in our sample did indeed benefit from spending time in urban green areas, as found in previous studies [38,42]; second, we investigated whether respondents displayed a preference for the different proposed scenarios described above. It is important to recall that the scenarios subject to comparison were equivalent in terms of thermal output, while they differed aesthetically and in terms of architectural structure. Therefore, our analysis aimed to assess whether, ceteris paribus in terms of thermal improvement, greener scenarios were preferred to more artificial ones. Moreover, we explored whether there were differences between subjects in terms of basic socio-demographic characteristics, namely age (18–25, 26–40, 41–65, over 66), gender, and educational level (<higher education, higher education) both in terms of perceived benefits from exposure to green areas and in terms of preferences toward a given scenario. Throughout the analysis, subjects with missing values on the variables of interest and those who answered "don't know" or "neither scenario" were dropped. Summary statistics of all variables used in the analysis are presented in Table 3.

Table 3. Summary statistics of the sample.

	N	%
Gender		
Women	609	71
Men	249	29
Age		
18–25	107	13
26–40	227	27
41–65	461	54
≥66	61	7
Education		
<Higher education	432	50
Higher education	427	50

3. Results and Discussion

3.1. Site Selection

Site selection relied on microclimatic analysis of the area, implemented by means of ENVI-met simulations. The results allow for preliminary evaluation of the thermal comfort conditions of citizens during the summer. Consequently, it was possible to define which were the most critical areas during both the day and the night. The results showed that during the day the most critical areas were in the south; during the night this part of the district seems to be a little bit more livable. In the northern area, the conditions are completely opposite, that is, more livable during the day and less so during the night. This configuration is consistent with the land use map identifying the southern part of the area as the less vegetated one (Figure 5).

The 24-h first simulation completed for the whole area highlighted that the lower residential area of the district (located between Via Cornigliano from the North and the railway line from the South) is the one with the worst thermal comfort.

An in-depth analysis of the simulation results allowed the identification of three specific intervention sites: A (Piazza Moisello), B (Piazza Battelli), and C (Via Giovanni d'Acri). In order to define the three intervention sites, the outdoor comfort level was evaluated through the UTCI parameter (Universal Thermal Comfort Index) as suggested by EU COST Action 730; this parameter considers the relationship between air temperature, mean radiant temperature, relative air humidity, air speed and water vapor pressure [50].

The UTCI for 2:00 p.m. on the day of 1 August 2020 showed values ranging from a minimum of 28.67 °C to a maximum of 42.19 °C (Figures 6 and 7).

The three sites identified are named, respectively:

- Site A (Piazza Moisello);
- Site B (Piazza Battelli);
- Site C (AMT parking lot).

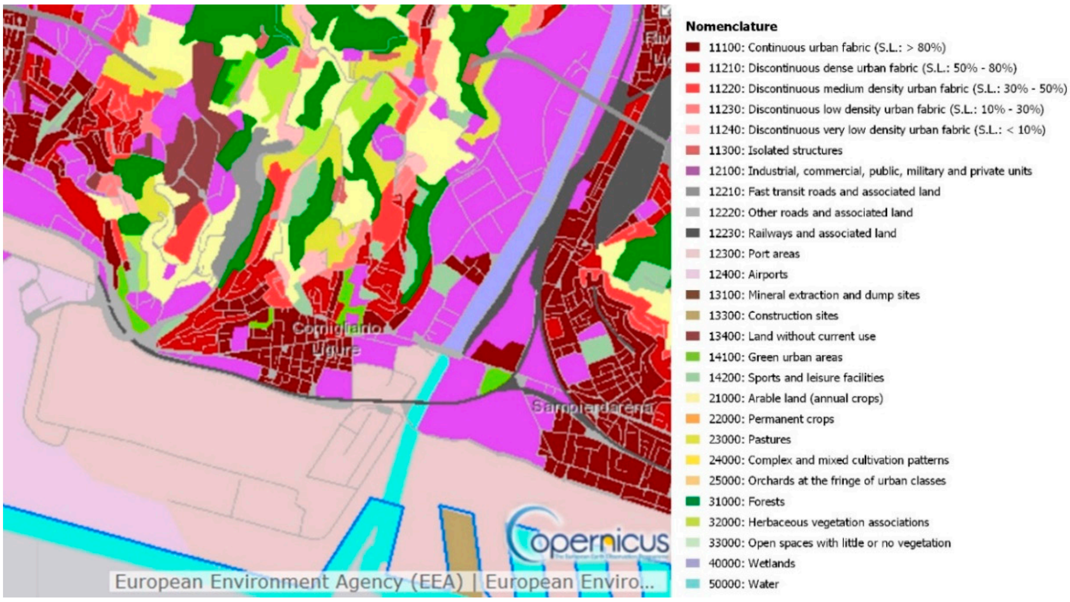

Figure 5. Land use map from Copernicus for the area of Genova Cornigliano.

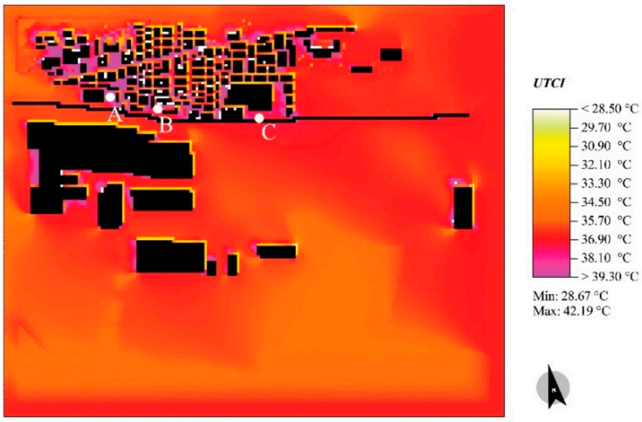

Figure 6. Output of the preliminary CFD simulations for the case study area (UTCI) at 2:00 P.M.

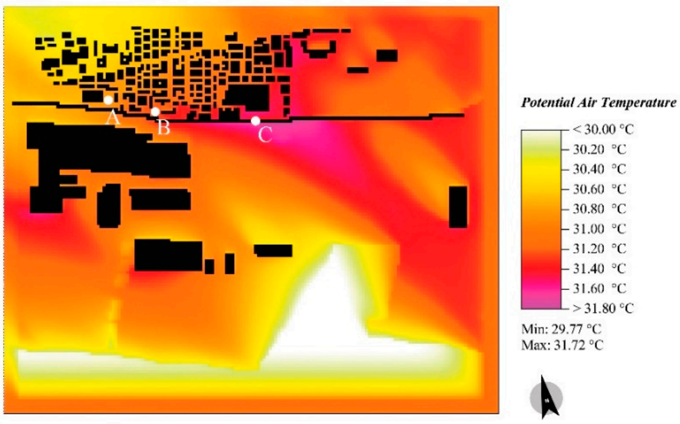

Figure 7. Output of the preliminary CFD simulations for the case study area (Potential air temperature) at 2:00 P.M.

In their current state, the UTCI parameters for the three specific named sites reached the following respective values: 40.410 °C; 39.271 °C; and 38.167 °C, defining a very marked level of thermal discomfort (Table 4).

Table 4. Microclimatic output values for the three points of the case study.

	Date	Time	UTCI (°C)	Mean Radiant Temperature (°C)
Point A	01.08.2020	12.00.00	39,097	62,294
	01.08.2020	14.00.00	40,410	65,304
	01.08.2020	17.00.00	33,558	35,669
	01.08.2020	21.00.00	28,104	21,983
Point B	01.08.2020	12.00.00	37,890	62,222
	01.08.2020	14.00.00	39,271	65,236
	01.08.2020	17.00.00	32,552	35,627
	01.08.2020	21.00.00	26,861	21,941
Point C	01.08.2020	12.00.00	35,664	61,983
	01.08.2020	14.00.00	38,167	65,005
	01.08.2020	17.00.00	36,430	62,639
	01.08.2020	21.00.00	24.894	21.810

3.2. Thermal Comfort and Microclimate

Following site selection, simulations were carried out for all the nature-based solutions listed above (Figure 4), in order to identify the best-performing ones in terms of microclimate regulation and thermal comfort improvement (potential air temperature distribution and UTCI) during summer and then formulate the two design scenarios for each site. The results of the ENVI-met simulation outputs showed that the most effective NBS for thermal comfort improvement and microclimate regulation during a hot summer day include the use of trees or shelters with climbing plants (due to their shading effect), with a change in UTCI of more than 5 °C in the hottest hours (Tables 5–7, Figures 8–10).

Table 5. Data from CFD simulation for all the NBS listed for Site A (with the most relevant results highlighted in grey) for a hot summer day at 2:00 P.M.

		Potential Air Temperature (°C)	UTCI (°C)
1.	Current state	31,524	41,207
2.	Ponds	31,358	41,073
3.	Trees	31,055	36,200
4.	Shrubs	31,133	37,574
5.	Green roofs	31,352	38,294
6.	Green facades	31,530	40,615
7.	Paving	30,571	40,505
8.	Shelter with climbing plants	31,035	36,386
9.	Grass	31,489	40,891

Table 6. Data from CFD simulation for all listed NBS for Site B (with the most relevant results highlighted in grey) for a hot summer day at 2:00 P.M.

		Potential Air Temperature (°C)	UTCI (°C)
1.	Current state	30,777	40,915
2.	Ponds	30,691	40,264
3.	Trees	30,544	34,033
4.	Shrubs	30,670	37,354
5.	Green roofs	30,375	40,272
6.	Green facades	30,464	40,282
7.	Paving	30,475	38,378
8.	Shelter with climbing plants	30,585	35,004
9.	Grass	30,752	40,114

Table 7. Data from CFD simulation for all listed NBS for Site C (with the most relevant results highlighted in grey) for a hot summer day at 2:00 P.M.

		Potential Air Temperature (°C)	UTCI (°C)
1.	Current state	31,472	40,147
2.	Ponds	30,971	39,725
3.	Trees	31,100	34,914
4.	Shrubs	31,101	37,444
5.	Green roofs	31,159	40,029
6.	Green facades	31,157	40,031
7.	Paving	30,655	39,451
8.	Shelter with climbing plants	30,724	34,437
9.	Grass	30,560	39,306

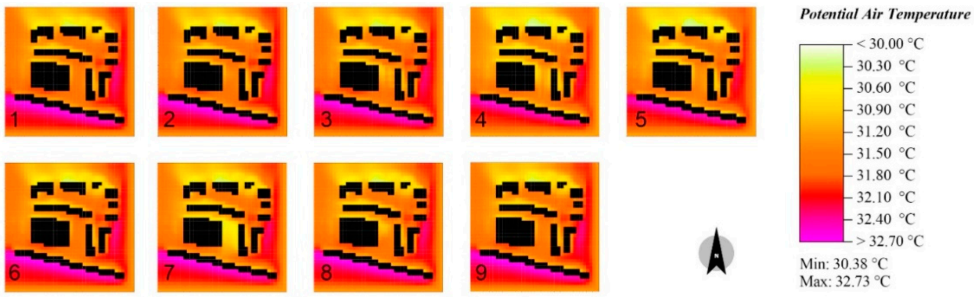

Figure 8. Simulation outputs for all the listed NBS for Point A, hot summer day.

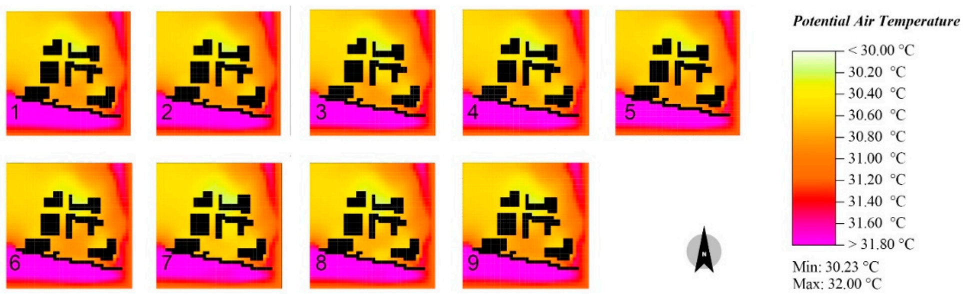

Figure 9. Simulation outputs for all the listed NBS for Point B, hot summer day.

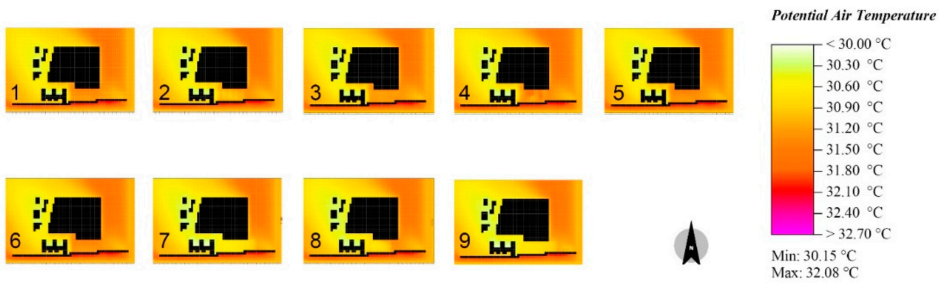

Figure 10. Simulation outputs for all the listed NBS for Point C, hot summer day.

Regarding the other solutions assumed (ponds, shrubs, green roofs and facades, paving with high albedo, and grass) we observed small variations of performance in terms of improvement of comfort conditions (UTCI level) between the different sites, as shown in Tables 5–7. These results may be related to the proximity of the sites analyzed, which had minor differences in terms of urban morphology, the building and natural context surrounding them (e.g., airspeed and direction), and the limited shading effects that ensure thermal comfort increase.

Starting from the simulation outputs, the most effective design scenarios were drafted. These were the ones integrating trees and canopies with climbing plants as main elements, combined with other solutions depending on the peculiarities of each site and following the urban constraints posed by the three different locations such as, for example, the presence of public services and road passage (Figures 11–14).

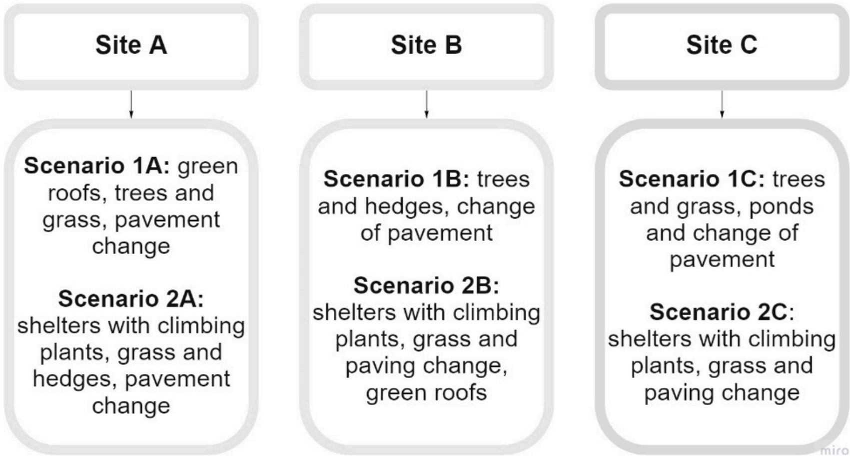

Figure 11. Specific configuration of the design scenarios for the three sites.

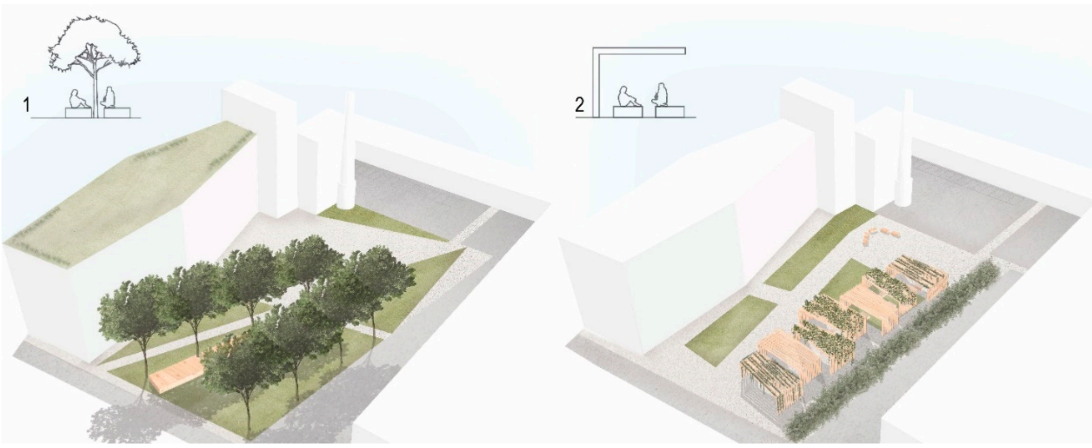

Figure 12. The two different design scenarios for Site A.

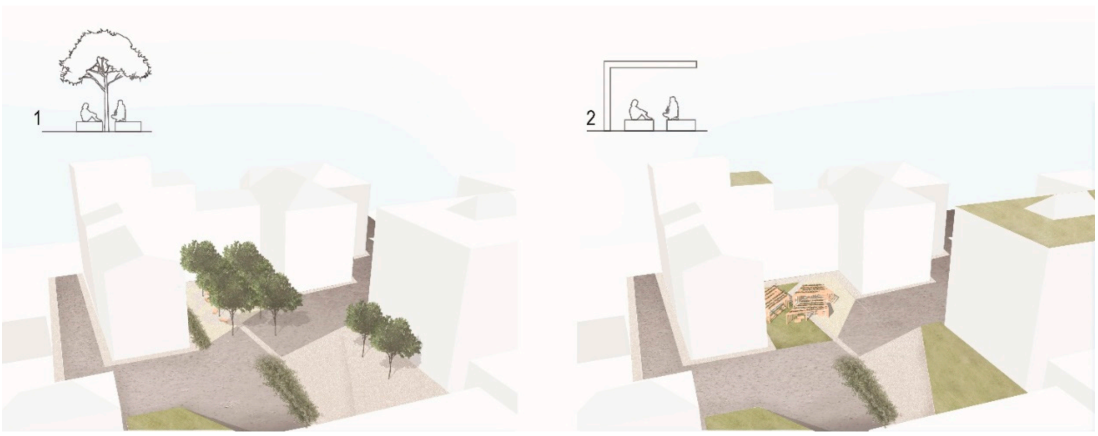

Figure 13. The two different design scenarios for Site B.

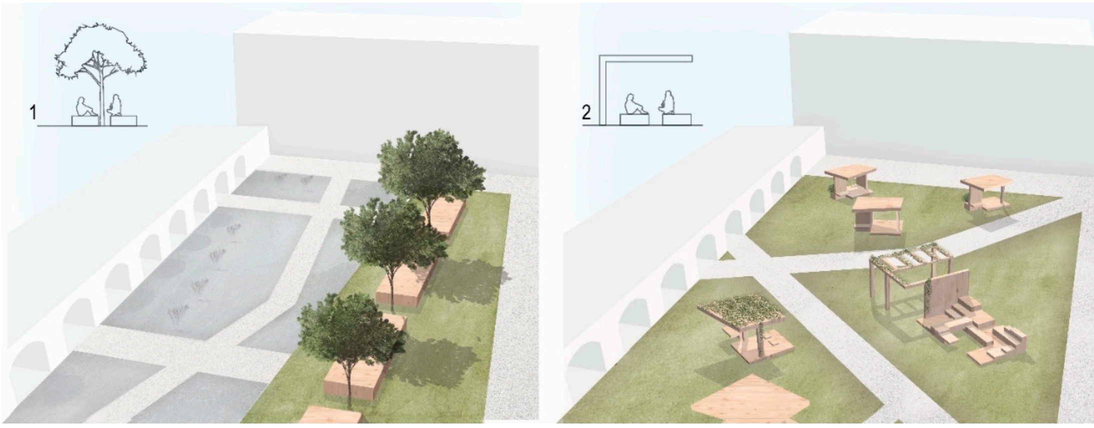

Figure 14. The two different design scenarios for Site C.

In the assumed design scenarios, the UTCI decrease (and relative comfort rise) calculated for each site at the specific points where the solutions were applied were as follow (Figures 15–17):

- Site A: from 41.60 °C to 35.85 °C for scenario 1A (trees) and 35.91 °C for scenario 2A (shelters).
- Site B: from 40.59 °C to 35.49 °C for scenario 1B (trees) and 35.08 °C for scenario 2B (shelters).
- Site C: from 40.14 °C to 34.43 °C for scenario 1C (trees) and 33.57 °C for scenario 2C (shelters).

Figure 15. Comparison between the current state and the two design scenarios for Site A, hot summer day at 2:00 P.M.

Figure 16. Comparison between the current state and the two design scenarios for Site B, hot summer day at 2:00 P.M.

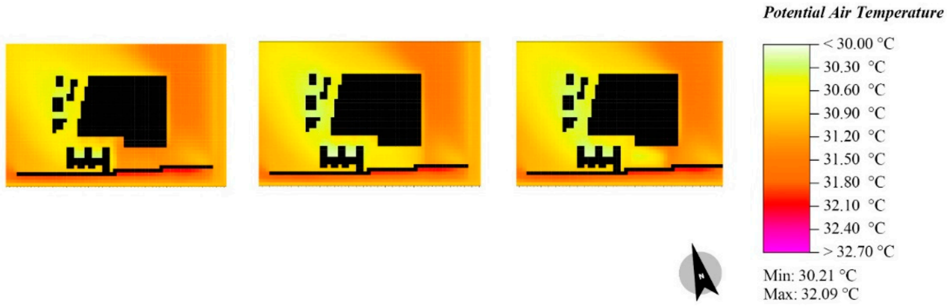

Figure 17. Comparison between the current state and the two design scenarios for Site C, hot summer day at 2:00 P.M.

The comparison between the current state and the design scenarios for the three sites (A, B, C, for a hot summer day) shows that the assumed combinations of NBS has a consistent improving effect in terms of increased microclimatic comfort. Specifically, this improvement turns out to always be not less than 5 °C compared to the starting UTCI for both scenarios in all three sites.

Finally, other simulations for standard summer and winter conditions were run. Simulations for standard summer conditions showed that the thermal comfort improvement for the two design scenarios were similar to hot summer conditions; for example, for Point A, the UTCI at 2:00 p.m. for Scenario 1A was 26.95 °C, and for Scenario 2A 26.85 °C, compared to 29.2 °C for the current state. In parallel, the results of the simulations related to the winter condition showed that NBS introduction does not imply an increase in thermal discomfort (which in some cases can be caused by the shading of buildings); for example, for Point C the UTCI values were 16.98 °C for the current state, 17.02 °C for Scenario 1C and 17, 35 °C for Scenario 2C.

3.3. Perceptive Benefits Evaluation

Our data agreed with previous studies [45] showing that subjects reacted very positively in terms of mood improvement when walking in green areas. Indeed, on a scale from 1 to 5, we found an average score of 4.65 across the sample; the considerable skew of the variable towards higher values indicates that many subjects found that this activity improved their mood. Thus, it appears that green areas have positive repercussions for psychological well-being. Moreover, the data showed that the result is robust across different socio-economic backgrounds. As can be seen from Table 8, the average values of the variable of interest are high regardless of age, gender, or level of education. Women seem to appreciate green areas somewhat more than men, while in terms of age it appears that the group that most benefits from green areas are those between 41 and 65 years old, while younger individuals between 18 and 25 years old benefit the least. Moreover, subjects with less than higher education express slightly greater mood improvement compared to more highly-educated subjects. However, for all three variables the differences among groups are quite small and suggest a generalized positive association between walking in a green area and mood improvement.

If subjects find that walking in a green area leads to mood improvement, it is plausible that among the different design scenarios they will prefer the one portraying a more natural environment. Our data support this expectation, as the design scenario evaluations showed that the interviewees preferred scenarios with trees as opposed to canopies with climbing plants. Specifically, for all three comparisons the overall preference for the scenarios with trees ranged from 72% to 84%. Thus, most subjects in the sample clearly preferred scenarios with trees (1A, 1B and 1C) compared to the more artificial alternatives (2A, 2B and 2C). It is critical to point out that all paired scenarios have the same characteristics in term of thermal comfort improvement, and would all increase the objective physical well-being of the subjects who were to visit them. However, the analysis presented here seems to suggest that it is possible to achieve a further improvement in subjective well-being by choosing scenarios that people find more pleasing.

Table 8. Average mood improvement when walking in green areas, by gender, age group and level of education (min. 1; max. 5).

	Mean	SD
Gender		
Women	4.73	0.57
Men	4.55	0.65
Age		
18–25	4.55	0.71
26–40	4.64	0.61
41–65	4.75	0.55
≥66	4.65	0.62
Education		
<Higher education	4.85	0.58
Higher education	4.64	0.63

Table 9 shows that this result is consistently found among both women and men and among subjects with lower and higher education, with only minor differences. In contrast, we observe somewhat larger differences in preferences among subjects in different age groups. As can be seen in Figure 18, which shows the preference of subjects for the different scenarios by age group (%), while all groups clearly favor the more natural solution, among the younger age group the gap between the two scenarios is smaller compared to the other groups, as the 18 to 25 age category has a slightly higher preference for the shelter scenario. This peculiarity occurs in all three cases and can offer food for thought on the greater preference on the part of young people (18–25 years) for scenarios with green solutions more integrated into artificial elements compared to the older age groups. A further interesting finding occurs among the over-66 age category, for whom a clear preference for the more natural scenarios can be observed in cases 1B–2B and 1C–2C, with a less marked preference in the case of scenarios 1A–2A. One of the possible explanations for this "anomaly" is that scenario A was characterized by the inclusion of a stretch of water, which is more attractive for younger people but which, for older people, may possibly be cause for safety concerns.

Table 9. Preference for paired scenarios by gender and level of education (%).

	1A	2A	1B	2B	1C	2C
Gender						
Women	79	21	86	14	86	14
Men	77	23	89	11	91	9
Education						
<Higher education	78	22	86	14	90	10
Higher education	79	21	88	12	86	14

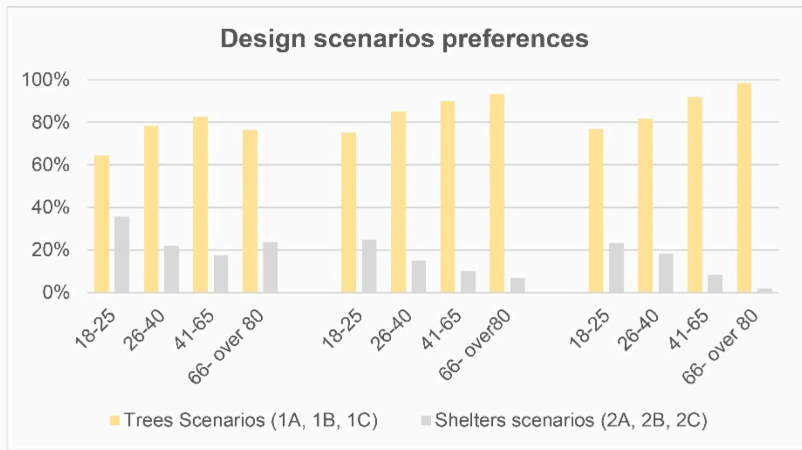

Figure 18. Bar graph showing the relationship between design scenario preferences and age group.

4. Conclusions

The study adopted an analytical approach to examine the current conditions of a dense urban area on a district scale, to select hotspots for urban regeneration, and to evaluate the performances of different design scenarios. The results demonstrate that although plant and natural elements in an urban context entail an overall improvement in the site's conditions (e.g., an increase in biodiversity and air quality improvement [7]), the adopted approach can play a key role in solving specific issues such as UHI and discomfort conditions. At the same time, the study deepens the interaction between the more technical and compositional/aesthetic aspects of urban design, highlighting that these two aspects must be considered in parallel in order to improve the wellbeing and livability of urban areas.

The following conclusions can be drawn:

- Simulations for the three specific sites showed that the best performing (NB) solutions in mitigating local UHI and improving thermal comfort during the summer are those that introduce shaded areas, such as trees and shelters with climbing plants;
- For the case study analyzed, urban morphology partly influences the performances of the NBS in terms of improving thermal comfort;
- Survey results showed that the sample population highly preferred scenarios with a high component of natural elements concerning urban regeneration intervention (even if the sample is not representative);
- The perception of people about the role of vegetation in improving mood and well-being is very positive;
- What emerges from the analysis of the variables defining microclimatic and perceptual wellbeing is that even though design scenarios entail the same (or very similar) physical performance (e.g., microclimate regulation), users can have a clear preference toward one. Therefore, the study highlights the effectiveness of considering different kinds of variables to define human wellbeing in urban design.

It is worth mentioning that the survey used for this study to evaluate perceptive benefits of NBS could be even better exploited by considering a higher number of design cases. This would allow deepening respondents' preferences and relative reasons and achieving more reliable results through a more elaborate analysis on a larger scale. Further research could also focus on defining and parametrizing the performances of the NBS in terms of thermal comfort and UHI reduction. In this perspective, further research could lead to defining general criteria for urban greenery intervention or guidelines for participation of citizens in urban design processes, also considering the socio-demographic context.

The results of this research are relevant for architects and designers as well as for sociologists and urban planners in relation to the identification of strategies for urban regeneration with a focus on citizen wellbeing and UHI mitigation.

In addition, the methodology proposed may also be considered as a starting point for new transdisciplinary research on the assessment of the various benefits of NBS on the environment and human health (as in the present research, developed thanks to the collaboration between architectural technology and sociology).

Author Contributions: Conceptualization, F.M., K.P., G.M.D.S. and A.G.; methodology, F.M, K.P. and G.M.D.S.; Site selection, F.M. and K.P.; Thermal Comfort and Microclimate, F.M. and K.P.; Evaluation of Perceptive Benefits: F.M. and G.M.D.S.; writing—original draft preparation, F.M.; writing—review and editing, K.P., G.M.D.S. and A.G.; visualization, F.M. All authors have read and agreed to the published version of the manuscript.

Funding: This research was developed within the Climaction Project. Financial support was provided by the University of Genoa, Dipartimento Architettura e Design (FRA funding, 2020).

Institutional Review Board Statement: Ethical review and approval were waived for this study due to the fact that no potential risks were present for participants and no sensitive information was surveyed. Subjects were informed of the objectives of the study and expressed their consent by self-enrolling and agreeing to participate in the survey. Moreover, no personal data were collected. Therefore, the resulting survey data are completely and irreversibly anonymous and it is not possible to identify the individuals who participated in the survey.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Conflicts of Interest: The authors declare no conflict of interest.

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