Chapter 54
A Systematic Catalogue of Design Solutions for the Regeneration of Urban Environment Contrasting the Climate Change Impact

Roberto Bologna and Giulio Hasanaj

Abstract The article illustrates a research for the definition of a catalogue of design solutions for climate change adaptation in the process of urban regeneration, reducing the vulnerability to climate change impacts and increasing the city resilience. Based on the analysis of relevant case studies of architectural and urban projects in the main biogeographical regions of Europe, the paper describes the research methodology applied for the construction of a catalogue of spatial and technological adaptive design models mainly focusing on the category of "nature-based solutions" but also considering "artificial solutions". In order to assess their effectiveness, different design alternatives are tested in a specific urban contest (a school courtyard in the City of Scandicci–Metropolitan City of Florence) prone to climate hazards of urban heat islands and pluvial flooding, simulating the impact on the more vulnerable user (children between 11 and 14 years old). For an adequate performance evaluation of multi-hazard effectiveness of the different adaptive design solutions, appropriate IT software and procedural models have been applied: ENVI-met microclimatic simulation software for thermal analysis and predictive method for hydraulic assessment. By comparing the results before and after the application, the climate-adaptive performance of alternative design solutions is measured through specific indicators. This approach is coherent to the design process management aiming to a predictive definition of performance evaluation through procedural models and digital instruments in order to properly address the complexity of architectural and urban project. The systematic catalogue of adaptive design solution offers useful tools and methods to designers and decision makers for the construction of climate change adaptation and mitigation plans in order to build a healthy and safe urban environment for citizens and drive an ecological and sustainable transition to green cities.

Keywords Systematic catalogue · Adaptive design solutions · Climate change · Urban regeneration · Resilience

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54.1 Introduction

In the next years, the climate change will continue to affect urban settlements with increasing violence and worsening impacts in terms of heat waves, heavy rainfall, drought and windstorms (IPCC 2021). In this scenario, cities represent the main human habitat, where most of the world's population lives, and the place of concentration of those impacts due to the presence of sensitive elements (people, buildings and infrastructures) that exacerbate the climate risks (UN-Climate Change 2020).

The scientific literature–especially those on climate science, environmental design and urban ecology–highlights the opportunity to develop the urban design in terms of resilience and adaptation to the effects of climate change. Important international experiences demonstrate the added value of the adaptive design approach, which combines urban regeneration with the aim of reducing climate risks. The adaptation plans developed in the cities of Barcelona, Copenhagen, New York and Rotterdam have demonstrate the importance of environmental design as a driver for reducing vulnerability and enhancing the built environment (Losasso et al. 2020). In addition, the new European Climate Change Adaptation Strategy (EC 2020) has given to adaptive design a central role in reducing the impacts of climate change and emphasized the need to: (i) develop site-specific studies in various urban settlements to define adequate regeneration strategies to different climatic, environmental and socio-economic characteristics; (ii) identify appropriate tools and methods to monitor the performance of adaptive solutions. The challenge focus on preparing cities and public buildings such as hospitals, schools, universities, housing and urban spaces to cope with current and future extreme events (EEA 2020; Tucci 2019).

The paper describes the research concerning the climate change adaptation and in particular focuses on project interventions (see Sect. 54.2) and design solutions (see Sect. 54.3) for increasing resilience in the urban environment, with the aim of cities adaptation.

The importance of the topic is widely recognized by international agreements, frameworks and policies that include in their priorities the development of actions to tackle climate change impacts affecting the urban environment (UNFCCC 2015; UN General Assembly 2015).

The research was developed within the PhD programme of Architectural Technology at the Department of Architecture (DIDA) of the University of Florence and find its roots in the national research PRIN2015 "Adaptive design and technological innovations for the resilient regeneration of urban districts in climate change regime", which the authors have participated in. While the PRIN2015 research has defined strategic orientations and design principles to cope with the climate change adaptation on vulnerable urban districts in order to demonstrate the reduction of exposure to extreme climate events, the PhD research has developed an analytic catalogue of adaptive design solutions and evaluated their effectiveness to tackle the extreme climate events in public spaces.

54.2 Case Study Analysis of Climate Change Adaptation Projects

The research starts from the analysis of case studies of adaptation projects based on recognized international best practises in the field of climate change adaptation. The research has focused on European continent in order to: (1) provide a comparable framework of interventions; (2) analyse the most frequent climatic hazards in the different biogeographical regions; (3) study the interventions realized in urban contexts similar to those of Italian cities.

From the analysis, it has been possible to identify 14 case studies concerning: three urban parks, three climate neighbourhoods, three projects in public spaces and five projects on buildings. The interventions are located in 11 European cities, within nine different countries and three different biogeographical regions (Atlantic, Continental and Mediterranean) (Fig. 54.1). The belonging of a specific geographical region has allowed to identify various climatic hazards and determine different strategies and design solutions not always practicable in other climatic areas. The project interventions were analysed at different scales, from the urban district to the building, and through a critical reading that has highlighted technical and procedural design solutions characterized by a holistic and ecosystemic approaches.

The research has identified six projects located in central urban areas and eight in peripheries, underlining a wide diffusion of adaptive interventions in the suburbs. This outcome represents a good practise in the interventions of urban renovation of marginal and/or degraded areas because it permits to combine climatic targets with

Fig. 54.1 Location of case studies of adaptation project in the European continent. *Source* Author's elaboration

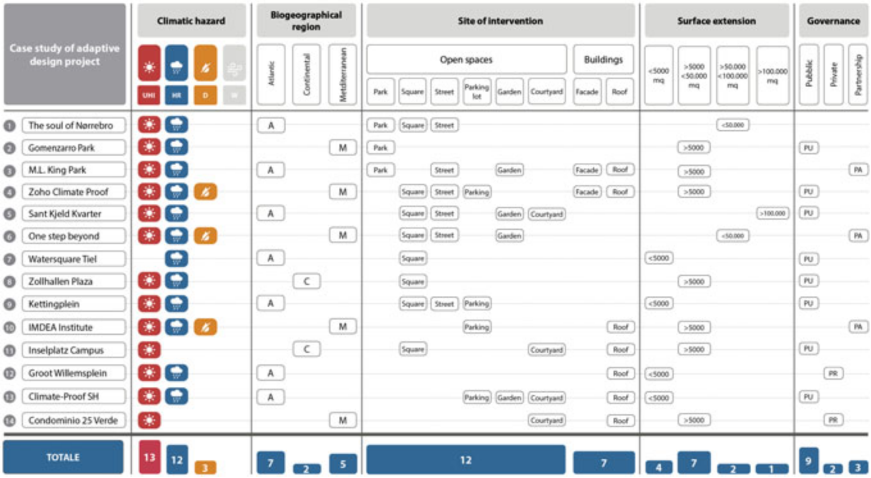

Fig. 54.2 Results of the case study analysis of climate adaptation interventions in European continent. *Source* Author's elaboration

economic, social and environmental objectives, providing benefits for the context where the project is located.

The results of the first part of research have shown that the most faced climatic hazards are urban heat islands (UHI; 13 cases out of 14) and pluvial flooding (PF; 12/14). Furthermore, it has observed that the analysed projects in most of cases (11/14) work to counteract both the hazards. Within this framework, the interventions on the climate-adaptive district of Zoho in Rotterdam, the redevelopment project "One step beyond" on the urban axes of Athens, and the Imdea Institute building in Madrid are exemplary cases because they attempt to respond also to drought issues (Fig. 54.2).

The adaptive design projects have found a wider application in the open spaces rather than in the buildings, and it has been interesting to note that most of the projects involve more than one element of urban space (Fig. 54.2). This result emphasizes two fundamental key parameters for the study of climate adaptation in urban contexts: on the one hand, the surface extension, and on the other, the systematic approach of the adaptive design interventions, that has confirmed the importance of the infrastructural actions, especially those with the use of nature-based solution such as green infrastructures.

Among the 14 case studies, nine projects were developed by public bodies, two by private companies and three by partnerships (Fig. 54.2). This result highlights the relevance of public governance in urban adaptation interventions. However, to achieve an effective level of climate resilience, the interventions in public space should be accompanied by incentive actions on private spaces.

54.3 Systematic Catalogue of Design Solutions for the Regeneration of Urban Environment Contrasting Climate Change Impacts

The analysis of the case studies led to identified 21 technological and spatial design solutions divided into two main categories, the "nature-based solutions" (NBS) and the "artificial solutions" (Fig. 54.3). The NBS include solutions "inspired and supported by nature, which are cost-effective, provide simultaneous environmental, social, and economic benefits, and help build resilience" (EC 2016). These solutions are excellent alternatives for restoring natural ecosystems and promoting sustainable development (Faivre et al. 2017; Mussinelli et al. 2018). Artificial solutions, on the opposite, are technical elements, coming from industrial processes (e.g., cool materials or permeable pavements) or architectural construction, characterized by a high level of engineering (e.g., urban floodable basins, urban canopies, water mirrors and underground water-collection tanks).

The 11 NBS identified include: trees, natural floodable basins, wetlands (ponds), bioswales, green roofs, vegetated ditches, urban farms, green walls, rain gardens, permeable green surfaces and drainage trenches. The artificial solutions collected are 10, among which we find: underground water-drainage boxes, underground water-collection tanks, cool materials, urban canopies, fountains, permeable pavements, water flow regulators, overground water-collection tanks, water mirrors and urban floodable basins.

The 21 design alternatives identified were further described in detail, forming a catalogue of technological and spatial solutions to address the climate adaptation

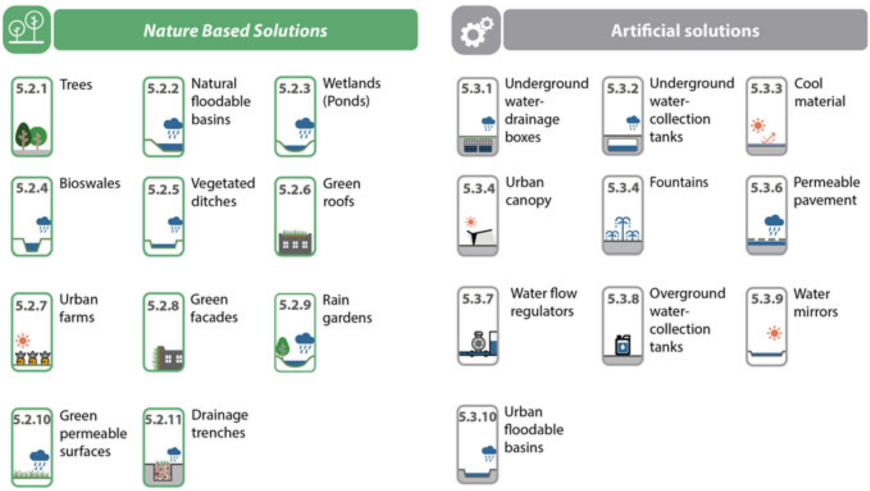

Fig. 54.3 Panel of adaptive design solutions identified from the case study analysis. *Source* Author's elaboration

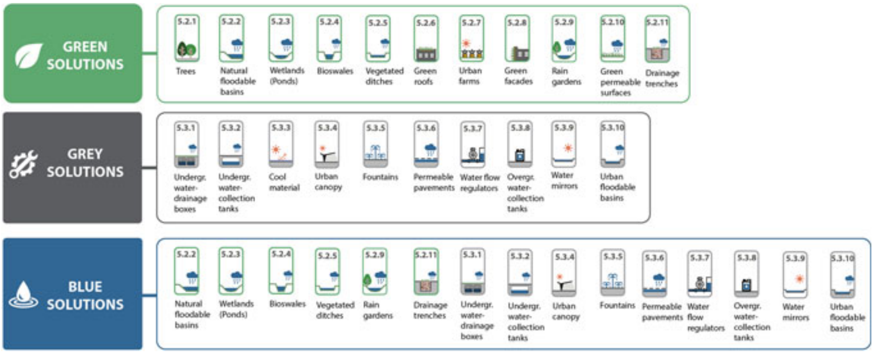

Fig. 54.4 Classification of the adaptive design solutions according to typology. *Source* Author's elaboration

project. From the creation of the catalogue, it has been possible to organize the different design solutions according to typology, category of intervention, site of intervention, contrasted hazards, working mechanisms and performance indicators.

The typology arranges the solutions into three groups: green, grey and blue solutions (Fig. 54.4). This further classification stems from the need to identify an appropriate group for design solutions, both natural and artificial, that have demonstrated a marked aptitude to tackle pluvial flooding, the blue solutions. Instead, green solutions are characterized by natural elements while grey solutions mainly include artificial components.

The category of intervention defines the correlation between the design solution and the spatial model of on-site implementation, allowing to organize the solutions into 4 groups of elements: punctual, linear, surfaced and volumetric (Fig. 54.5). Punctual solutions include trees, water flow regulators, and overground water collection tanks. Linear solutions contain bioswales, vegetated ditches and drainage trenches. Surface solutions include urban canopies, green roofs, urban farms, green walls, green surfaces, cool materials and permeable pavements. Volumetric solutions contain natural floodable basins, ponds, wetlands, rain gardens, underground water-drainage boxes, underground water-collection tanks, fountains, water mirrors and urban floodable basins.

The site of intervention identifies elements of urban open spaces and parts of the building where adaptive solutions can be integrated (Fig. 54.6). The first includes parks, gardens, squares, parking lots, streets and courtyards; the latter refers mainly to the building envelope, including facades and roofs. It is interesting to observe that the most integrable solutions are trees, permeable green surfaces, cool materials and water flow regulators. On the contrary, the least integrable solution are essentially those with a higher demand of free space such as natural floodable basins, green roofs, and green walls.

The classification according to the climate hazards has shown that 16 solutions are able to respond to UHI, 17 solutions work against PF, four alternatives cope to tackled droughts and two work to counteract windstorms (Fig. 54.7). The result highlight

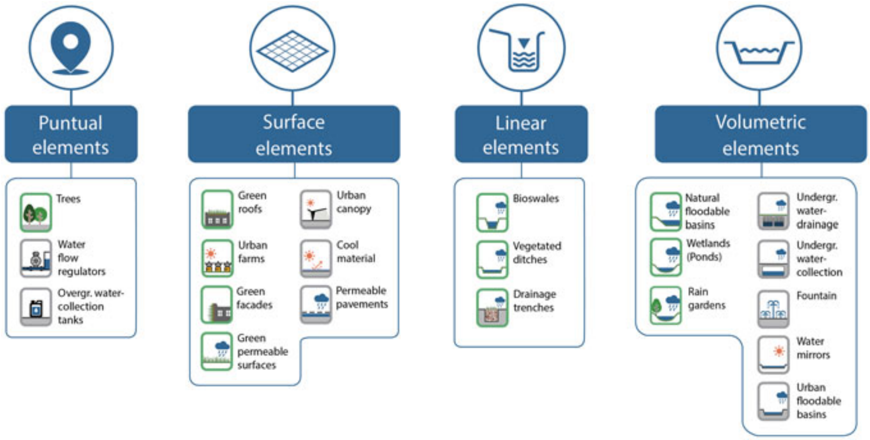

Fig. 54.5 Classification of the adaptive design solutions according to categories of intervention *Source* Author's elaboration

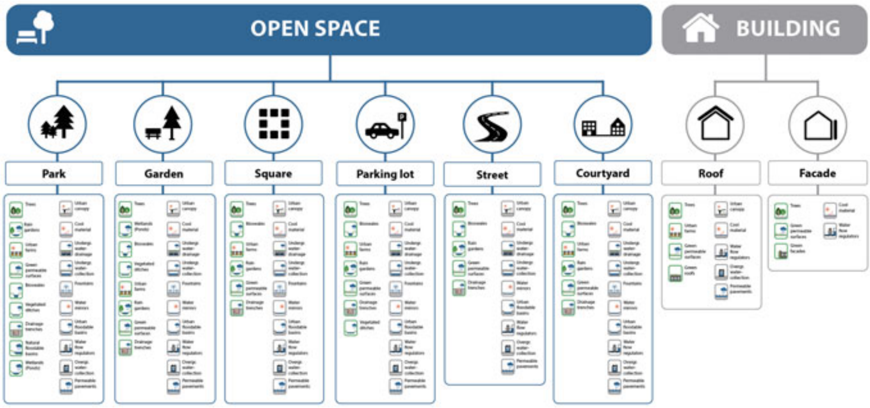

Fig. 54.6 Classification of the adaptive design solutions according to site of intervention. *Source* Author's elaboration

once again that the most addressed climatic hazards refer to thermal and hydraulic stress. Moreover trees, underground water-collection tanks, urban canopies and urban floodable basins are able to respond to three different climatic hazards. Instead, drainage trenches, underground water-drainage boxes, cool materials, fountains and water flow regulators are the unique solutions that address a single climatic hazard.

The analysis on the working principles of the design solutions has allowed to identify the adaptive mechanisms used to counteract extreme events (Fig. 54.8). The results have shown that the adaptive actions employed to counteract extreme temperatures include shading, reflection, absorption and thermal emission. Among these, absorption represents the most frequent principle, while shading, which occurs

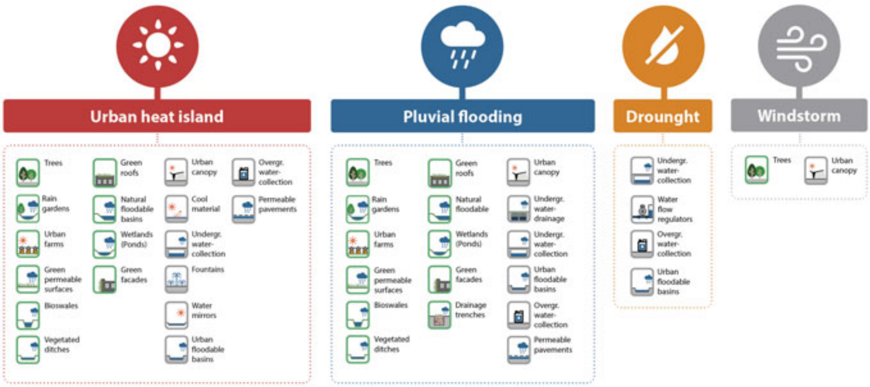

Fig. 54.7 Classification of the adaptive design solutions according to climatic hazards. *Source* Author's elaboration

more rarely and is implemented only by trees and urban canopies, represents a key factor for thermal reduction and increased well-being. Regarding pluvial flooding, the adaptive mechanisms include interception, collection, infiltration and runoff, with a homogeneous distribution of the adaptive actions over all solutions. The adaptive mechanisms of drought phenomena concern collection, reuse and reduction of water resources. While for windstorms, the only adaptive actions concern the windbreaks barrier effect. Adaptive mechanisms for droughts and windstorms are limited and do not allow to define primary and secondary working principles.

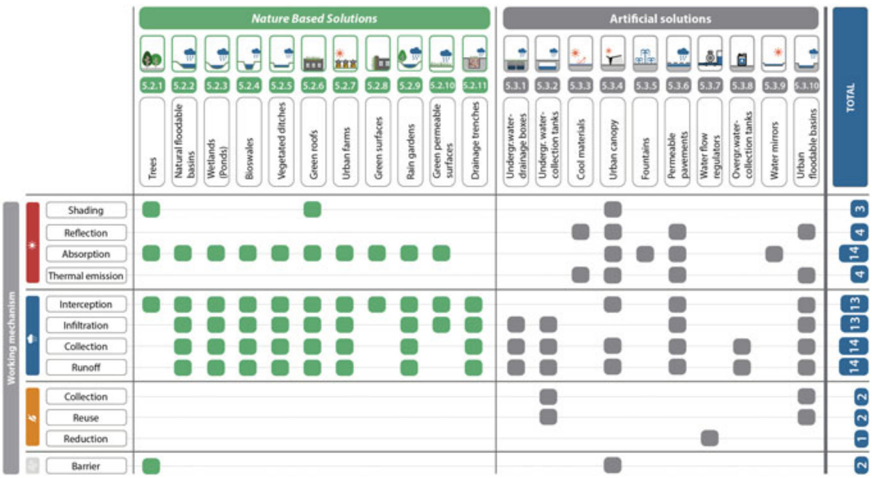

Fig. 54.8 Working principles of the adaptive design solutions according to the different climatic hazards. *Source* Author's elaboration

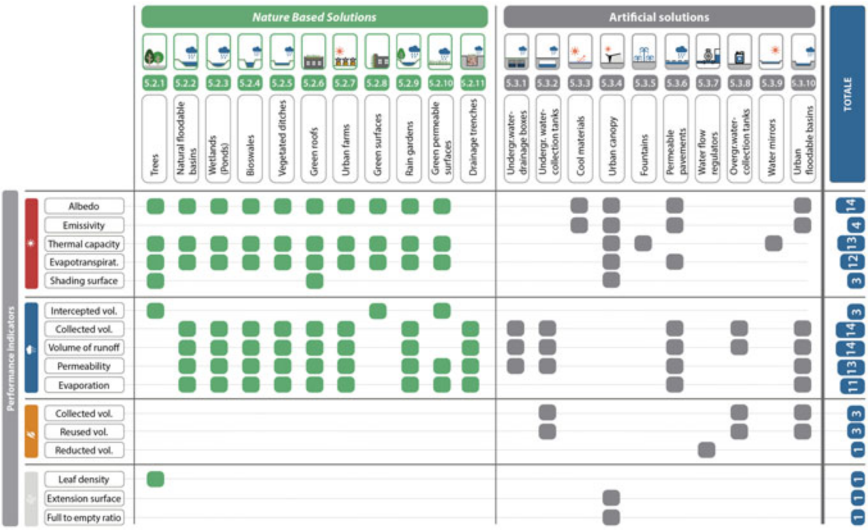

Fig. 54.9 Performance indicators of the adaptive design solutions according to the different climatic hazards. *Source* Author's elaboration

The performance indicators allow, on the one hand, to measure the effectiveness of the solutions, and on the other hand, to identify the key parameters to increase the climate-adaptive performance (Fig. 54.9). Regarding the UHI, the main performance indicators refer to: albedo, evapotranspiration and thermal capacity. In the PF, indicators include intercepted and collected volume of water, runoff, permeability (measurable through infiltration rate) and evaporation. For drought, the indicators refer to the volume of water collected, reused and reduced. While for windstorms include leaf density, extension surface and the full to empty ratio.

Matching all the information provided in the catalogue of design solutions for climate adaptation, it is possible to define many different multidimensional matrices. For example, it has been possible to identify the most appropriate solution for a given urban space and climate hazard (Fig. 54.10).

54.4 Performance Evaluation of Different Adaptive Design Solutions

In the last part of the research, has been measured the effectiveness of four different adaptive design solutions (trees, green surface, permeable pavement cool material and rain garden) from those collected on the catalogue. The aims of this phase have been the following: verify the application of the different technical alternatives identified, measure their effectiveness in terms of reduction of thermal and hydraulic hazards, and define a replicable methodology for evaluating performance effectiveness.

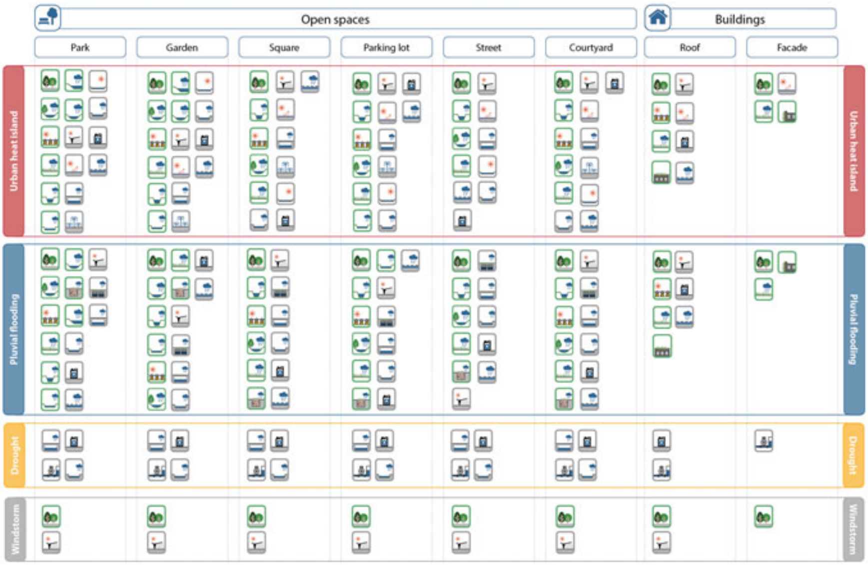

Fig. 54.10 Example of multidimensional matrix for a given urban space and climatic hazard *Source* Author's elaboration

The experimentation has identified as testing area the courtyard of the middle school "E. Fermi" in the Municipality of Scandicci (Metropolitan City of Florence) (Fig. 54.11) prone to climate hazards of UHI and PF, simulating the impact on the more vulnerable user (children between 11 and 14 years old).

54.4.1 Methods and Tools for the Performance Evaluation

The effectiveness of the adaptive solutions has been evaluated using the microclimate simulation software ENVI-met, for thermal analyses, and the predictive method, for hydraulic behaviour. The different solutions have been tested through simulations and measurements "ex ante-ex post" that has allowed to evaluate the effectiveness through comparison of performance indicators. The indicators used for the thermal analyses were potential air temperature, mean radiant temperature (MRT), Predicted Mean Vote (PMV) and Physiological Equivalent Temperature (PET). Among these, only the first one represents a physical indicator, while the others are indicators related to outdoor comfort. For the hydraulic analysis, the indicator used has been the runoff coefficient, which measures the percentage of incident rainwater on a given surface that is neither infiltrated nor evaporated and is transformed into surface water runoff (EEA 2021; Moccia and Sgobbo 2016).

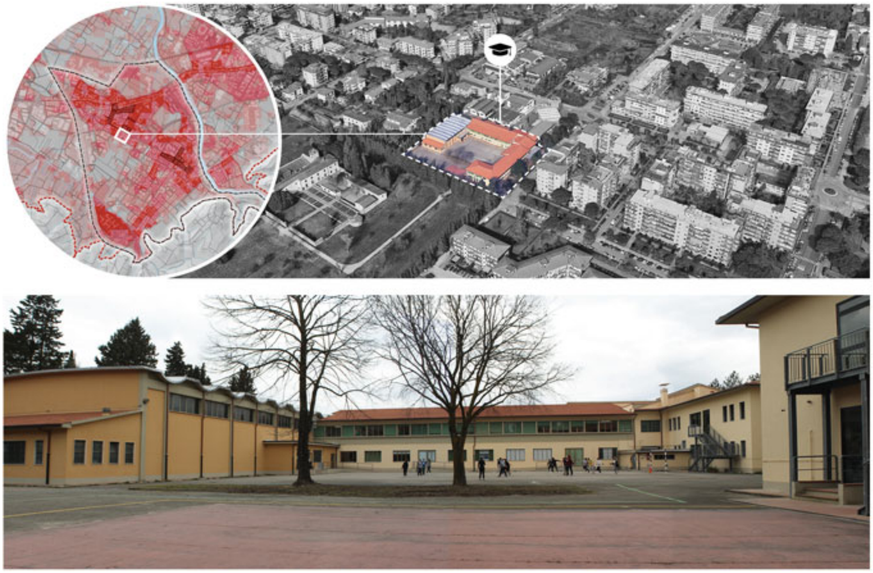

Fig. 54.11 Testing area of the schoolyard located in the Municipality of Scandicci. *Source* Author's elaboration

54.4.2 Results of Climate-Adaptive Performance on Four Design Solutions

The results of the thermal simulations have been extrapolated as graphical elaborations, in form of general plans (Fig. 54.12), and with tables (Fig. 54.13), referred to the centre of the testing area (coordinates $i = 30$, $j = 33$, $z = 4$). The outputs have been processed at 2 p.m. to ensure full solar exposure of the experimental area for the day August 1, 2021, corresponding with the presence of a heat wave.

Microclimatic simulations have shown that the major reduction values of the potential air temperature were obtained with the permeable cool material pavement in which is measured a reduction of − 0.46 °C, while the green surface has been the less effective solution, measuring a reduction of − 0.24 °C (Fig. 54.13). These results are justified due to the different amount of incident energy that is reflected from the solutions surfaces (albedo): in fact, for the cool material, the albedo value is 0.80, while for the green surface is 0.20. The results referred to the outdoor comfort indicators (MRT, PMV and PET) have shown similar results in terms of perception of well-being on the vulnerable user. The solution that provides the highest level of comfort is the rain garden, while the less effective is the permeable cool material pavement, which records in the MRT index a worsening value compared to the original state and increase the discomfort perception (Fig. 54.13).

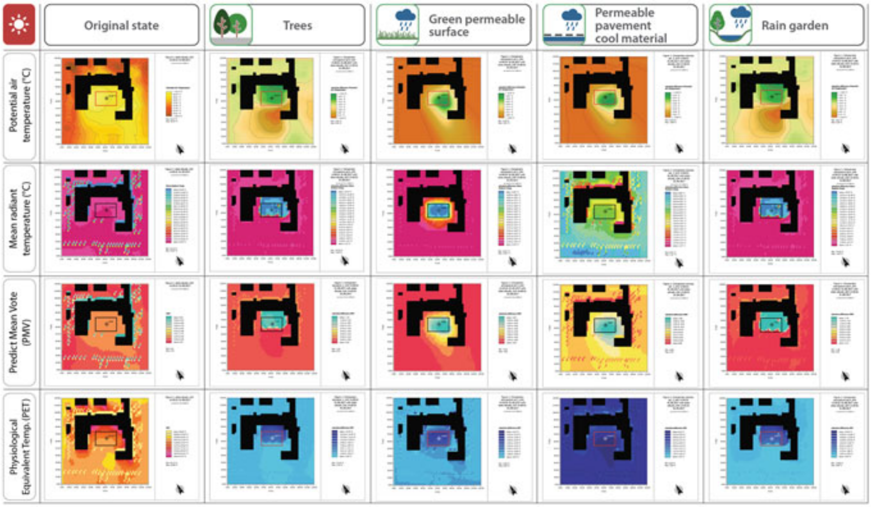

Fig. 54.12 Comparison of the thermal simulations: extrapolations in form of graphical elaborations. *Source* Author's elaboration

	Original state	Trees	Green permeable surface	Permeable pavement cool material	Rain garden
Potential air temperature (°C)	36,27	35,99	36,03	35,81	35,83
		- 0, 28	- 0, 24	- 0, 46	- 0, 44
		good	good	very good	very good
Mean radiant temperature (°C)	74,75	54,32	73,84	75,70	51,18
		- 20,43	- 0,91	+ 0,95	- 23,57
		very good	insufficient	insufficient	very good
Predict Mean Vote (PMV)	5,33	4,21	5,25	5,28	3,98
		- 1,12	- 0,08	- 0,05	-1,35
		very good	insufficient	insufficient	excellent
Physiological Equivalent Temp. (PET)	52,52	44,92	52,23	52,76	43,25
		- 7,60	- 0,29	- 0,24	-9,27
		good	insufficient	insufficient	very good

Fig. 54.13 Comparison of the thermal simulations: extrapolations in form table. *Source* Author's elaboration

According to Nardino et al. (Nardino and Laruccia 2019) and Bruse et al. (Bruse and Fleer 1998), the measured reductions achieved by trees and rain gardens guarantee the change on thermal class of comfort and allow to demonstrate the effectiveness of the solutions. Conversely, the only application of cool material pavement and green surface doesn't provide an adequate performance to face the UHI effect.

Therefore, the widespread application of materials with high solar reflectance (high albedo), such as the cool material pavement, is surely able to reduce the air temperature but leads to a worsening on the user perceived comfort. In the gap between the reduction of physical and comfort indicators, the architectural project assumes a central role, which requires (case by case) an adequate site-specific assessment, considering the needs of vulnerable users, the context where it locates, and without being a simple substitution of parts with high-performance adaptive solutions.

In hydraulic evaluations, the analysis has been focused on the global value of runoff in the schoolyard, where surface testing area and runoff coefficient of the solutions deeply affect the performance. The testing area is 600 m^2 for all solutions except trees (where is considered the on-ground projection of their crown of 423 m^2), while the runoff coefficient is identified since scientific literature.

The results of hydraulic evaluations have shown that in the original condition, where the courtyard is covered with impermeable concrete, an overall runoff value of 88% is measured (Fig. 54.14). The most effective solution has been the rain garden with a runoff coefficient of 0.10, achieving a global value of runoff of 71% and a reduction of − 17%.

The less effective solution has been the permeable cool material pavement that, with a runoff coefficient of 0.60, achieves a global value of runoff of 82%, with a reduction of − 8%. Although the performances achieved by the four tested solutions are different, contrary to what observed for the thermal responses, all the design alternatives are effective to contrast the risks of PF.

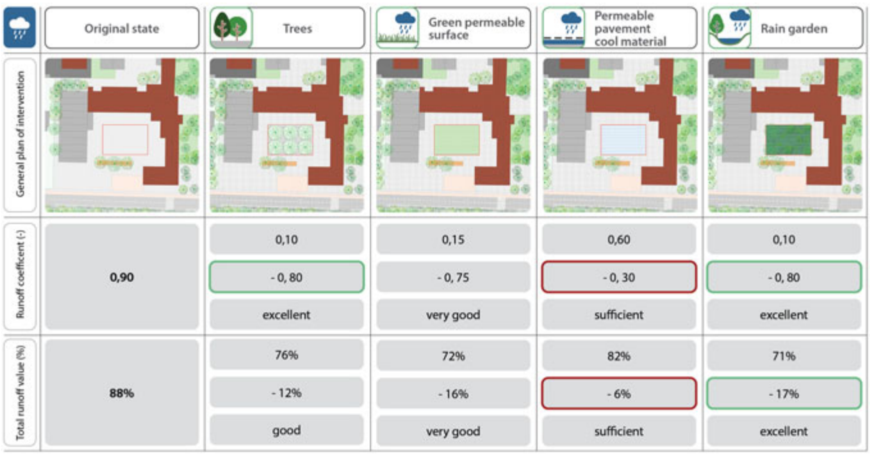

Fig. 54.14 Comparison of the hydraulic evaluations. *Source* Author's elaboration

54.5 Conclusion

The research moves from the analysis of case studies for climate adaptation in order to define a homogeneous framework of interventions in the main biogeographical regions of Europe. The identified projects represent good practises on climate adaptation, are recognized by the main international bodies, refer to the different urban areas of the contemporary city, and work to counteract one or more climatic hazards. These results have been fundamental to define the adaptive strategies and solutions for the regeneration of urban areas able to counteract the extreme events of climate change.

Further investigation should be carried out on the management, maintenance and costs of implementation of the different case studies on which, especially in the more complex interventions, significant investments are often required. Another observed critical aspect is the shortage of adaptation projects facing windstorm effects. This issue is also confirmed by the last report on the adaptation of cities in Europe and represent on the one hand, a limitation on knowledge, considering the increase in the number and intensity of such extreme phenomena, and on the other, an interesting field of experimentation where future research should be oriented.

The catalogue of design solutions–the main research output–identified 21 different technical and spatial alternatives to address projects based on climate resilience and adaptation. This result represents a useful tool for designers and decision-makers to identify the most appropriate and effective solution according to typological (NBS/artificial or green/grey/blue solutions), spatial (category and site of intervention) and technical-performative (climatic hazards, working mechanisms, performance indicators) parameters. Furthermore, the catalogue provides a relevant contribution for the new adaptation strategy of the EU, which has accelerated the implementation of adaptation actions and requires innovative solutions, tools, and methods suitable to guide the urban regeneration towards the green cities.

The experimental research results led to evaluate thermal and hydraulic performance of the different design alternatives and define a replicable model to measure their effectiveness in terms of adaptation through IT tools and predictive methods. The digital transition addresses the design process towards innovative approaches: through simulation and modelling methodologies, digital technologies become an integrated system for the decision-making in the different phases of the building process.

Research's limitation about the real effectiveness of hydraulic behaviour refers to runoff indicator. Although the calculation methodology is scientifically recognized, it represents an expeditious procedure, in which each surface area is associated with a coefficient obtained from the scientific literature that allows to reach a global value of the surface runoff. In this practical method the contribution of the sewerage system is not considered, and this leads to a less accurate assessment compared to hydraulic studies performed with the more complex software (Hec-ras, Epanet, etc.).

Finally, the catalogue of adaptive design solutions includes appropriate alternatives to tackle windstorm and droughts, able to reduce the vulnerability to the specific climate hazards, but their effectiveness was not evaluated.

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