A simplified procedure to improve the usability of hydrodynamic modelling software in regenerative urban design

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A simplified procedure to improve the usability of hydrodynamic modelling software in regenerative urban design

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Abstract. Densely urbanized areas are greatly exposed to the risks from climate change as reported by IPCC in 2018. In particular, compact urban settings afflicted by heavy storms and droughts, coupled with the intensification of the Urban Heat Island (UHI) effect and incremental heat waves require a requalification of the outdoor environment that accommodates for both strategic water management and enhanced microclimatic conditions. The present study proposes simplified procedures to enable the application of complex hydrodynamic modelling software (SWMM), by non-expert users (such as planners and designers), in the preliminary phases of an urban space project according to a water-sensitive urban design approach. In the paper, Italian multi-level regulations aimed at controlling the impacts of excessive rainfall in urban areas are taken into account as well as the integration of circular water management systems with evaporative cooling strategies. The proposed procedure is focused on two aspects: 1- to simplify the steps needed to convert the existing climatic data to provide a numerical sequence, to insert into the software; 2- to define a set of pre-compiled and multi-purposed solutions toolkits for the design of urban spaces that can be imported into the software through an external database.

1. Introduction

Compact urban settings afflicted by heavy storms and droughts, coupled with the intensification of the Urban Heat Island (UHI) effect and incremental heat waves require requalification of the outdoor environment that accommodates for both strategic water management and enhanced microclimatic conditions. Under these conditions, a "regenerative" requalification approach best fits the task by proposing a process that mimics nature itself through restoration, renewal and revitalization of sources of energy and materials. Regenerative development aims to recognize humans as part of ecosystems by renewing ecological systems in a way that accommodates for continuous human intervention [1]. It revisits the human-nature relationships in socio-ecological systems that evolve over time to respond to the needs of society while safeguarding the integrity of the natural environment.

Regenerative design, similarly, seeks to restore the capacity and function of ecosystems, by design and improvement of the built environment. To that extent, buildings are not considered as isolated structures, but designed to work in a system-based approach with its surrounding environment, propitiating lasting future benefits between inhabitants, natural, and built environment [2] [3].

Meanwhile, in the short-term, regenerative design can also enhance the capacity of local urban areas to buffer seasonal flooding and reduce extreme heat events through solutions that provide multiple benefits (e.g. green roofs and pervious pavements). To do so, it is important to give practitioners tools that can aid them to incorporate these principles in early stages of the design process, not only to meet local regulations but to go beyond requirements and add outdoor thermal comfort targets. Some governments count on policy mechanisms like laws, building codes and tax rebates to guarantee that developers incorporate sustainable water principles in projects [4], [5], [6]. In the Italian context, the legal limits associated with the rule of hydraulic and hydrological invariance prevent and mitigate the phenomena of flooding caused by the increase of impervious surfaces, and contribute to ensuring high levels of hydraulic and environmental protection. To foster an understanding of ecology and resources such as water and energy as part of the regenerative process of design is crucial to ensure that the outcomes have a positive effect on the climate and ecosystems alike [7]. Conventional – sometimes not sufficient approaches to water management in the urban environment involve heavy underground engineering interventions to control excess stormwater, which lose an opportunity to create quality outdoor spaces by cross-interacting with design disciplines. Outdoor water management is usually not addressed until later in most design projects, partially due to required expert knowledge and sophisticated procedures and software.

Simplified step-by-step procedures can increase the comprehension and usability by non-expert users (such as planners and designers). Among various tools - such as InfoWorks ICM, SOBEK, and Mike-SHE - the Storm Water Management Model (SWMM 5), open source software developed by the US Environmental Protection Agency (EPA), was selected to test a simplified procedure described in this paper. SWMM 5 has the capability of aiding design professionals in the preliminary phases of a project; at the same time, this procedure could be developed to improve microclimatic conditions.

2. Selection of a case study in northern Italy

The case study selected to test the procedure is a building in a square in the south part of Milan, Lombardy region, in North of Italy, a city with a population of almost 1.3 million people. The city of Milan represents an appropriate scenario to observe the UHI effect: the summer is generally hot and not particularly windy (averaging 1.8 m/s in the summer and a southeast direction); with mostly clear skies. Consequently, some urban areas are affected by elevated temperatures and humidity. According to the Koppen climate classification, Milan is located in a Cfa area characterized by a humid subtropical climate. Milan is quite far from the sea, with some continental characteristics, similar to much of Northern Italy's inland plains, where hot, humid and muggy summers and cold, wet winters.

Located in the south-east area of Milan, the Corvetto-Lodi neighbourhood is around 5 km from the city centre and hosts about 2.6% of the city's population. The neighbourhood is heavily built-up, with few green public spaces, poor wind circulation, and consequently affected by the UHI of Milan. Average Landsat-8 LST data for the area shows an average of 35-37 ºC for summer hotspot .

This part of the city is an area already undergoing several regeneration projects of public spaces and buildings. One of these renewal projects at Ferrara square will host the residence for 250 Politecnico di Milano students. This student residence is a suitable pilot case to do a preliminary assessment of rainwater harvesting and multipurpose reuse such as reducing extreme heat events (e.g., for passive outdoor water-cooling) in a preliminary phase, helping to apply the methodology proposed in this study.

3. Methodology proposed

The following step-by-step Simplified Procedure (SP) was developed for a training course, part of the Soloclim Research Programme (Horizon 2020 Grant No. 861119) aimed at designers and non experts in stormwater management and hydrodynamic modeling. Future development of the procedure would incorporate feedback loops that consider water reuse for water-based outdoor cooling (such as fountains and water mists).

Once the procedure is tested for more case studies, it can be published in an online platform, along with a supporting database containing green-blue toolkit solutions with predefined values that can be selected by designers and planners to be input in SWMM 5 and tested in the project. The development of the SP arises, primarily, from the awareness of the issues faced by practitioners, e.g. to find adequate rainfall data. Second, the selection of the different model components and parameters required specialized knowledge and support from expert software users. For this reason, the SP provides a series of simplified, pre-compiled and implementable solutions together with ready-to-use rain data able to simulate baseline scenarios and the addition of solutions. In the present paper and current stage of the research, the lot for the new Politecnico di Milano student residence in Corvetto-Lodi was selected as a case study to apply the simplified analysis and procedure consisting of the following stages (Figure 1).

The simplified procedure consists in the development of different steps from A to E and it is aimed at encouraging the use of simplified tools to control water volumes in urban areas. This approach can be coupled with solutions that improve microclimatic conditions in urban spaces (Step E), consequently increasing urban space liveability. In this ongoing research, steps F and G are not yet completed, i.e. only steps from A to E are highlighted and explained.

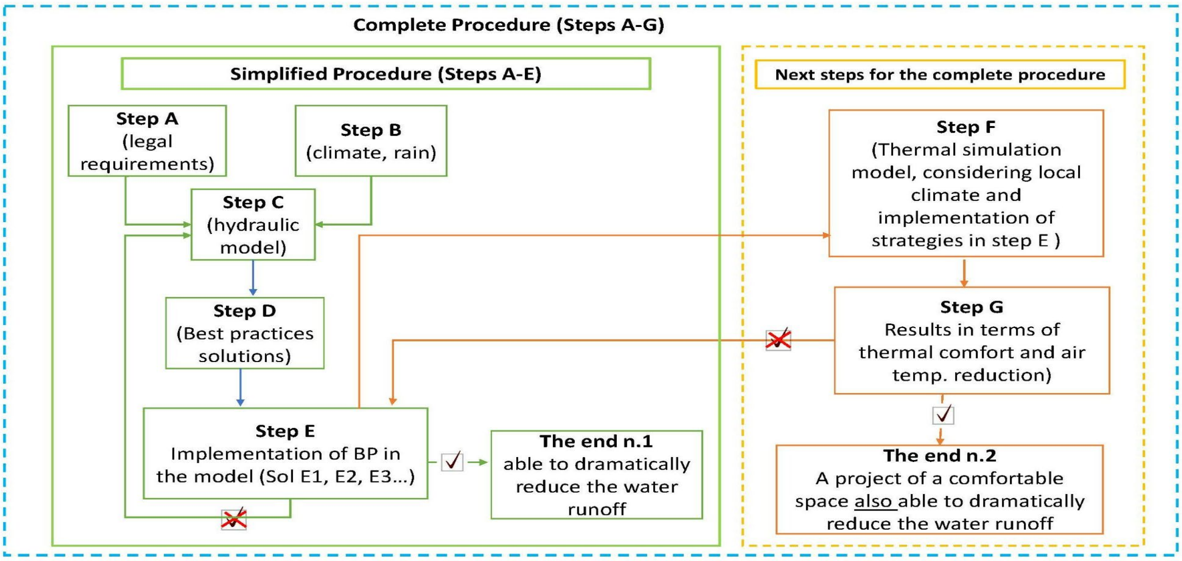


Figure 1. The simplified procedure proposed (steps A-E) together with next steps related to assessing thermal comfort in urban space (Steps F-G). The whole design process is aimed at generating urban spaces capable of reducing water runoff and summer heat stress

3.1. Step A - Identification of policy instruments or legal limits: In recent years, concerned with the safety of citizens, the Italian authorities have approved multi-level regulations targeted at controlling the impacts of excessive rainfall in urban areas. Since then, planners, architects, engineers and ecology experts have begun to address the theme of water-sensitive urban design, starting from the constraints expressed at a regional regulatory level. Similarly, local urban planning instruments and municipal building regulations adopt these same limits imposed on the region.

The corresponding measures of hydraulic and hydrological invariance are calculated considering the surface affected by recent interventions. The reduction of soil permeability due to implementation of these new surfaces is calculated in reference to pre-existing conditions of urbanization. In the case study selected, the total sealed surface is 1,829 sqm (1,283 sqm are roofs and 546 sqm are private open surfaces). Thus, the legal limit imposed in the Lombardy Region, calculated for the area of 2,273 sqm varies between 2.27 and 4.55 litres per second (lps), depending on the level of hydraulic criticality. The limit utilized for the SWMM 5 simulation and scenarios in this paper was 4.55 lps.

3.2. Step B - Identification of climatic data of extreme rain events: Raw precipitation data for extreme events provided by Lombardy's ARPA website (www.idro.arpalombardia.it) was used to simplify the steps needed to convert the existing annual climatic data (in this case, precipitation events) into a numerical sequence. The pluviometric intensity curve from ARPA was converted to a number sequence of 24 hourly values and then used in the simulation of the case study. The graph in Figure 2 (left) shows the resulting sequence associated with an extreme event with a return time of 100 years, and refers to the amount of rainwater per hour and accumulated expressed in mm over a 24-hour interval.

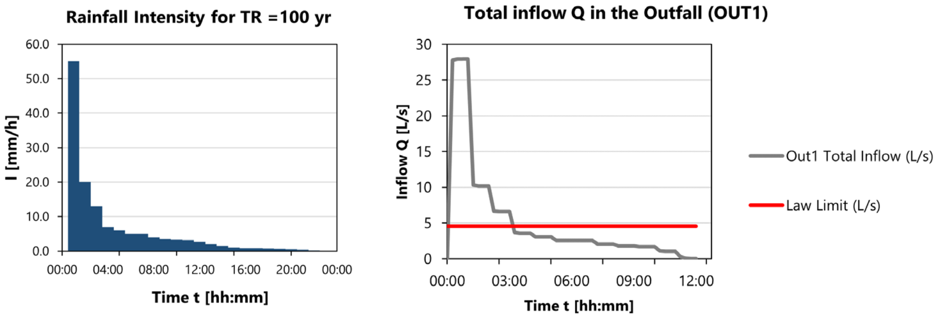


Figure 2. Pluviometric values (in mm) of rain over a 24-hour interval, associated with an extreme event with a return time of 100 years, related to the amount of rainwater /hr accumulated (left). In the right, total Inflow in the outfall of the lot’s catchment area (1,829 sqm).

3.3 Step C Simulation of the actual state and comparison with the legal limits: Instead of simulating a new model, the procedure gives the possibility to build or download simplified, precompiled and implementable water management schemes (model exemplified in the left, in Figure 3). The user will be asked to identify the most suitable scheme, follow the step by step procedures for its construction or download it and finally enter the actual surface area and specific characteristics of the chosen urban context. In this way the basic scenario is defined and simulated, and the water flows entering the sewer can be compared with the legal limits.

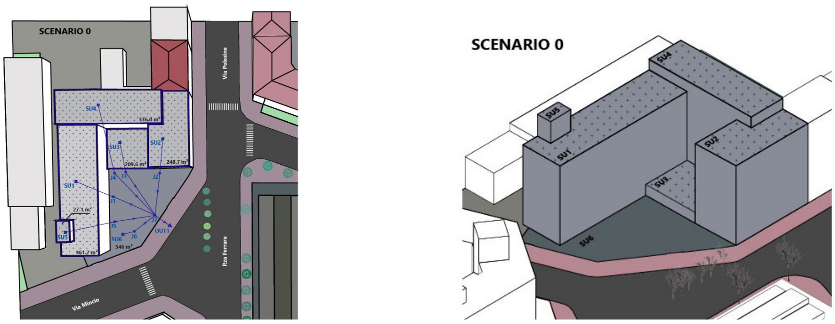


Figure 3. Schematic drawing of the case study: a building with 1,283 sqm of roofs (SU1 to SU5) and 546 sqm of paved courtyard (SU6). The plan (left) shows the scheme used to simulate the baseline scenario in SWMM 5, on the right the 3D lot view.

3.4. Step D Solutions associated with best practices: Once the baseline scenario was established in step C, the next phase of the research was to analyze best practices in the field of water management. Figure 4 shows a selection of solutions helpful to produce a set of pre-compiled and multi-purpose solution toolkits for the design of urban spaces that can be imported into the software through an external database. These solutions can be linked to the different nodes that build up the water management scheme and encompass SUDs best practices, as well as examples of water collection and storage. The SWMM 5 model defines these solutions as *Low Impact Development* (LID), techniques designed to capture surface runoffs and provide water detention, infiltration, and evapotranspiration.

Most of the solutions (listed below) that can be adopted in densely urbanized areas, may be modelled using 4 main strategies among the 8 available in the SWMM 5 catalogue: bioretention cells, green roofs, pervious pavements, and rain barrels (a water square can be modelled in the preliminary design phase using the information of the rain barrel). LID Controls are considered as properties of a given sub-catchment. Additionally, bioretention cells and pervious pavement can contain optional drain systems in their gravel storage beds to convey excess runoffs from the site and prevent flooding of the units. The information below was analyzed and extracted from [8], [9], [10], [11]:

3.4.1 *Bioretention Cells.* Bioretention Cells are depressions that contain vegetation grown in an engineered soil mixture placed above a gravel drainage bed. They provide storage, infiltration, and evaporation of both direct rainfall and runoff captured from surrounding areas. Rain Gardens are a type of bioretention cell consisting of just the engineered soil layer with no gravel bed below it.

3.4.2 *Green roofs.* Green Roofs are a variation of a bioretention cell that have a soil layer laying on top of a special drainage mat, that conveys the excess of rainfall. The adoption of green roofs has several benefits for the thermal balance of the building indoors and to the microclimate outdoors. In addition, and regarding water management practices, adopting green roof systems provides an extra cover of soil and plants that have the capacity to absorb and retain extreme rainfall.

3.4.3 *Pervious pavement.* Continuous Permeable Pavement systems are excavated areas filled with gravel and paved over with a porous concrete or asphalt mix. Usually, rainfall will immediately pass through the pavement into the gravel storage layer below it, where it can later infiltrate at natural rates into the site's native soil. Block Paver systems consist of impervious paver blocks placed on a sand or pea gravel bed and with a gravel storage layer below it. Consequently, the rainfall is captured in the open space between the blocks and later conveyed to the storage zone before native soil.

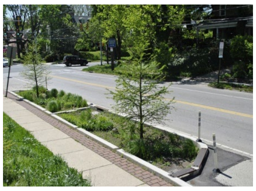
Green Roof (GRF1)	Bioretention Cell (BRC1)	Pervious Surf. (PEPAV 1)	Rain Barrel (RIBA1)
Planted surfaces in a layer of soil on top of roofs.	Rain gardens have extra layers for infiltration and filtration.	Permeable pavements or a mix between impervious and pervious surfaces.	Rain barrels are reservoirs connected to roofs (apparent or underground).
 Extensive green roof. Credits: ZinCo	 Rain garden. Queen Lane, Philadelphia (USA)Credit://wiki.sustaina ble technologies.ca	 Semi permeable surface. Calvados-Honfleur Business Park (France) Credit: //landezine.com/	 Water square in Rotterdam-NL. Runoff from roofs and squares are stored and slowly released.
 Intensive green roof. Credits: ZinCo	 Rain garden Paso Robles (USA)Credit:www.svrdesig n.com	 Pervious pavement. Portland (USA) Credit: www.portlandoregon.gov	 Cisterns connected to roofs in Austin (USA) Credit: www.austingutterman.com/

Figure 4. A selection of LID used for the application of the methodology proposed to the case study, including some good examples of implementation (Source: Gibelli, 2015).

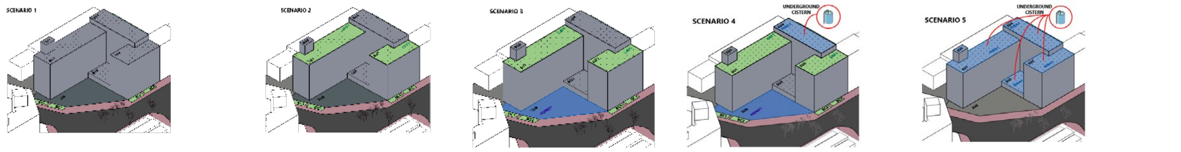
3.4.4 *Rain barrels.* Rain Barrels (or Cisterns) are containers that collect roof runoffs during storm events and can either release or re-use the rainwater during dry periods. Rain barrels usually contain a predetermined volume, adding extra wait to specific areas of the building. Alternatively, rain barrels may be located on the ground floor or below it, in case the building structure does not meet the conditions for adding extra weight. The SWMM 5 software considers a preliminary assessment of the volumes captured, however, it is up to the designer to integrate it in the urban environment. In this paper, suggestions are offered on how integrated solutions and tools may be applied as an urban regeneration strategy. Construction details remain out of this paper's scope.

3.5 Step E Transfer of good practices to the case study. To evaluate improvement with the implementation of a set of LID, a first simulation was carried out of the existing configuration of the square, considered a reference case (Scenario 0). The following four simulations carried out in SWMM 5 demonstrated the effectiveness of each solution and are described in Table 1.

Table 1. The combination of LIDs in the different scenarios. Scenario 0 is the current situation without any strategy aimed at stormwater management

LID	Scenario 0	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
Rain Garden	X	2 (25 sqm)	2 (25 sqm)	2 (25 sqm)	2 (25 sqm)	X
Green Roof	X	X	2 (700 sqm)	2 (700 sqm)	2 (700 sqm)	X
Pervious Surface	X	X	X	1 (546 sqm)	1 (546 sqm)	X
Rain Barrel	X	X	X	X	1 (336 sqm)	5 (1283 sqm)

3.6 Step F, G Evaluation of the thermal comfort of the urban space (under development): In addition to the SWMM analysis where we incorporate different LID in all 5 scenarios, there would be an evaluation of the thermal behavior of the project for each scenario (Step F). These simulations are run in the Envi-Met 4 software, simulating scenarios with the input of different thermal variables (air temperature, relative humidity, wind velocity, albedo of materials, etc.). Similarly, this analysis enables us to simulate not only the climatic conditions of the baseline scenario, but to verify improvements to the microclimate made by these solutions. Step G concerns testing and adapting solutions to meet optimum rainwater capture and acceptable thermal comfort.



View of Scenario 1, with 4 rain gardens	View of Scenario 2, with 4 rain gardens and 2 green roofs	View of Scenario 3, with 4 rain gardens, 2 green roofs, and pervious pavement.	View of Scenario 4, with 4 rain gardens, 2 green roofs, pervious pavement and a rain barrel.	View of Scenario 5, with rain barrels. RB could be located on the roof on the open space or underground

Figure 5. Axonometry of the existing condition and view of different scenarios that include LID for the water management simulated with the software SWMM.

4. Results

The results summarized in the graph in Figure 6 allow us to understand if the compliance of the water management with the regional law (previously defined and equal to 4.55 lps) is possible.

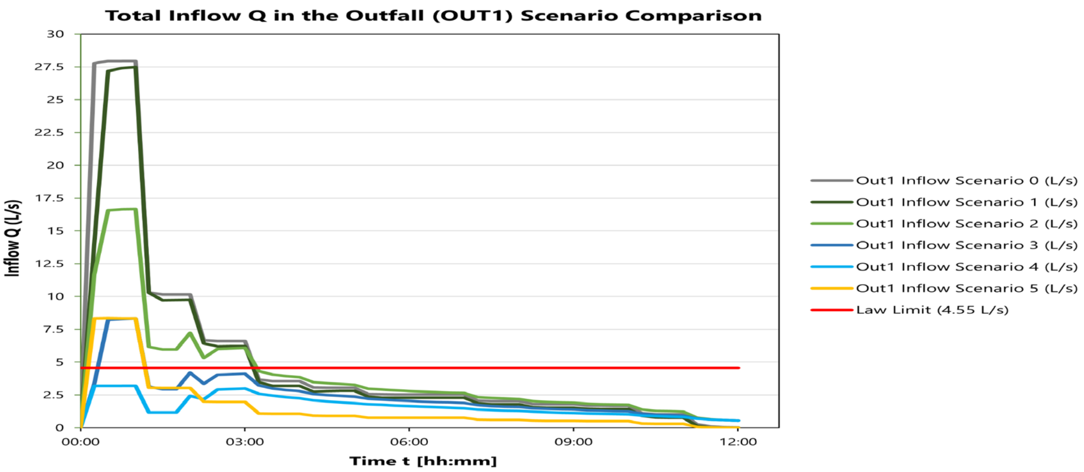


Figure 6. Comparison between law limit value and different scenarios concerning the implementation and/or combination of different strategies. The first thing to observe during the analysis is that although the graph (above) shows 12 hours of simulation, only the first 2 hours are truly significant. Most of the scenarios do not satisfy the law (it is very restrictive) and Scenario 0 presents an excess of more than 6 times the limit in the first hour.

In the analysis performed for Scenario 1 (dark green line), the results show that the rain garden's contribution to infiltration and runoff capture is insignificant. It is clear that rain gardens are too small or too few to be considered an effective solution. The Scenario 2 (light green line), which associates the presence of green roofs on 2 buildings with rain gardens, reports a value of lps 4 times higher than the law requirements. It significantly improves the previous scenario. Scenario 3 (dark blue line) which adds to the previous strategies' permeable pavements, has a peak of 8 lps, a value still too high to meet the legal requirements. By collecting the water in one of the roofs not occupied by a green roof, the best performance is achieved and the requirements of the law are finally met. Scenario 4 (light blue line), through the use of water collection on the roof, added to rain gardens, green roofs, and permeable pavements, has values below 4 lps in the most critical moments. The mere collection of water from the roofs, represented by Scenario 5 (yellow line), is also not sufficient. It is evident that an approach with diversified solutions proves to be much more effective than acquiring a single solution, as it is easier to divide the total amount of water from extreme events and comply with the principle of hydraulic and hydrological invariance for land use transformations. Another consideration, presented especially in Scenario 4 is the maximum effectiveness obtained with these combined-solutions for water storage and retention in amortizing inflow, as it tends to increase, due to later release of excess volumes from green roofs to the sewer system.

5. Conclusion

The methodology applied to the case study and the contribution due to the availability of simulation software is an approach that allows measuring the contribution from different points of view. Each implemented strategy defines design choices that can improve the functioning of the public space, but also its appearance and urban liveability (an aspect that includes thermal comfort). Although the methodology can be easily implemented in contexts other than Lombardy, we must carefully take into consideration the distinct aspects of the places from time to time: starting from the legislation on water management (which defines the specific requirements of the interventions), to the soil permeability specifications, the morphological characteristics. They affect the choice of strategies (LID) and consequently the possible physical configuration of the places and the impact on livability levels (thermal comfort).

In the case study presented in the paper, the compliance with legal requirements required intervention on the public space and the facing buildings. A single strategy is not enough (Scenarios 1 and 5), but a comprehensive and connected vision that involves many of the surfaces of public space is often required; according to the regenerative design approach, it also enhances the interrelationship between mitigation and adaptation to climate change (in particular with adequate water management and limitation of the overheating risks), especially is some water-based cooling systems can use collected water from the roofs.

If the exceptional event that forces strategies to work in synergy happens a few times a year, it is also true that much more often the same space should guarantee thermal comfort conditions for those who go to the urban space to spend spare time, or just to back home. For this reason, strategies, sizing, and localization should be part of a unique approach, as the proposed methodology in its entirety suggests.

Acknowledgements

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References

[1] Zari, M. (2010) *Regenerative Design for the Future*. Build 2010, 115, 68–69
[2] Kellert, S. (2008). *Dimensions, elements, and attributes of biophilic design*. Biophilic Design. 3-20
[3] Nicola Colaninno N., Morello E. (2019), "Modelling the impact of green solutions upon the urban heat island phenomenon by means of satellite data". In: *Journal of Phys.: Conf. Ser.* 1343. IOP Publishing
[4] Lombardy Regional Law of 15 March, 2016, no. 4. Testo coordinato del r.r. 23 novembre 2017, n.7
[5] Art. 2.3 of the Code of Virginia, titled "Stormwater Management Act"
[6] UK's Flood & Water Management Act 2010 (F&WMA 2010). Schedule 3 of the Act requires the inclusion of Sustainable Drainage Systems in https://www.storm-water.co.uk/legislation
[7] Zari M. (2018), *Regenerative Urban Design and Ecosystem Biomimicry*. Routledge, London, UK
[8] EPA (2015), *Storm Water Management Model (SWMM) version 5.1 User's Manual*. EPA, USA
[9] Carli, P. et alii (2019), "Design strategies to improve water resilience in urban areas. Good practices for an open-data culture of the urban environment". In: Angelucci. F et alii, *IFAU 2018. Second international forum on architecture and urbanism*. Gangemi, Rome, I
[10] Gibelli, G., Gelmini, A., Pagnoni, E., Natalucci, F., (2015) *Gestione sostenibile delle acque urbane. manuale di drenaggio "urbano". Perché, Cosa, Come*. Regione Lombardia, Ersaf, Milano
[11] Masseroni D., Gandolfi C., Bischetti G.B. (2018), *Manuale sulle buone pratiche di utilizzo dei sistemi di drenaggio urbano sostenibile*. CAP Holding spa