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Green buffer areas and green roofs: performance design to improve the urban water cycle

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Green buffer areas and green roofs: performance design to improve the urban water cycle

Elena Giacomello[1,*]

[1] Iuav University of Venice, Department of architecture and arts, Tolentini, Santa Croce 191, 30135, Venezia, Italy

*Corresponding author: elenag@iuav.it

Abstract. While in all Europe the land use does not decrease – contrary to EU soil strategy that would actualize the zero net land use by 2050 – cities are plagued by problems such as air pollution, urban heat island effect and uncontrolled run-off following intense rain events, which degrade the environment threatening the health and the safety of inhabitants. The impermeable materials and are responsible for the worsening of the urban water cycle and, at the same time, for the increase in summer air temperatures: both those effects can be mitigated by nature-based and draining solutions. The paper explains the hydrological phenomena of the urban impervious surfaces, highlighting the typical functional defects, providing then a list of various green technologies suitable to overcome the common issues of city centers like high density / reduced spaces, irreversible impervious surfaces, undersized drainage, presence of sub-structures / sub-systems, conservation of architectural heritage. The technical green solutions on the ground (bio-retention systems, rain gardens, trees, pervious pavements…) and on the roofs, specifically designed, behave 1) as a buffer for the stormwater and superficial run-off, being able to collect water, 2) as providers of side effects that can affect water quality, biodiversity, amenity in cities. Experimental results from a rain simulation are presented in order to argue potentials and limitations of these solutions, often narrated as salvific, or, on the contrary, underestimated in their technological specificities.

Keywords: SuDS-Sustainable Drainage Systems, Urban greenery, Green roofs, Run-off coefficient Urban water cycle

1. Introduction: land take and soil sealing

"Too few know that the thin layer that lies below our feet holds our future. Soil and the multitude of organisms that live in it and provide us with food, biomass and fibers, raw materials, regulate the water, carbon and nutrient cycles and make life on land possible." [1] p.1. With the Soil Strategy for 2023, European Commission-EU set fundamental goals regarding the protection, the sustainable use and the restoration of soil providing strategic objectives at medium and long period. Among the firsts is included "Reach good ecological and chemical status in surface waters and good chemical and quantitative status in groundwater by 2027", while among the seconds "Reach no net land take" [1] p.3. With this document the EU takes action against a progressive soil degradation in Europe, which, first of all, concerns the forestry and agriculture sector: "Net removals from LULUCF sector are on a worrying trend. Between 2013 and 2018, the yearly net carbon removals were reduced by 20%" [1] p.5. At the same time, limiting the land take and the soil sealing are defined as *priority actions*. "Soils provide the foundation of building and infrastructure. However when we seal soil to build on top, we are loosing irreversibly all its key ecosystem services, exposing cities to higher flood peaks and more intense heat island effects […] Urban sprawl and soil sealing consume nature and transform valuable ecosystems into concrete desert." [1] p.8.

Despite the EU having assigned clear soil protection objectives for the future, land consumption and soil degradation do not stop, indeed they increases on the European scale; among the degenerative processes "land conversion to artificial surfaces impairs the ecological functions of land and makes ecosystems less resilient. In Europe, this conversion takes place primarily in cities and commuting zones. Between 2012 and 2018, the net land take in the EU in these zones was 450 km^2 annually" [2].

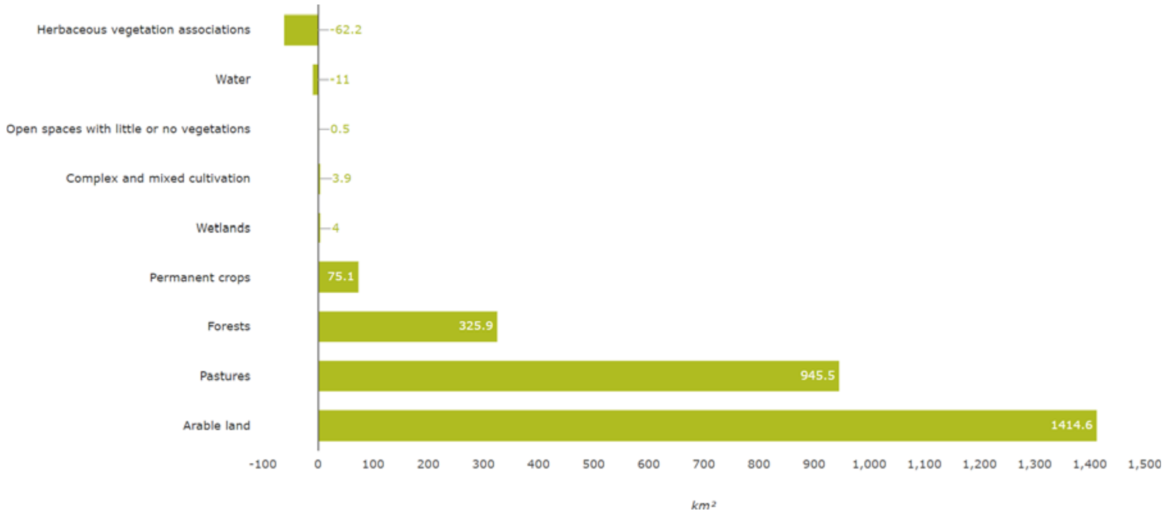

Figure 1. Net land take in cities and commuting zones by land cover category, 2012-2018, EU-27. Source: [2] Fig.1.

In Italy, the evolution of land consumption is even worsening: in 2022 it is increasing as never before with a speed of 21 hectare/day, highest value since 2012 (20 hectares per day had never been exceeded). The new artificial surfaces affected 2.4 m^2/sec, the yearly net land consumption was found to be 70.8 km^2, resulting in an overall yearly soil sealing growth of 22.3 km^2 [3] pp.15-16 (see Table 1). At the 2022, in Italy, the consumed land is equal to 21.500 km^2, i.e. the 7.14% of the entire national territory (see Figure 2). Table 1 provides the summary of Italian land consumption in the one year between 2021 and 2022 and Figure 2 the Estimated land consumed (2006-2022) as a percentage at national level.

Table 1. Italian land take in the one year between 2021 and 2022: land take (new surface area with artificial cover), net annual land take (difference between new consumption and areas restored in the previous year), of land take density (increase in square meters for each hectare of territory), overall waterproofing (conversion of natural areas or reversible land take into new permanent land take). Source: [3] p.15.

Land take (Km^2)	76,8
Net land take (Km^2)	70,8
Net land take (% increase)	0,33
Density of net land take (m^2/ha)	2,35
Total waterproofing (Km^2)	22,3

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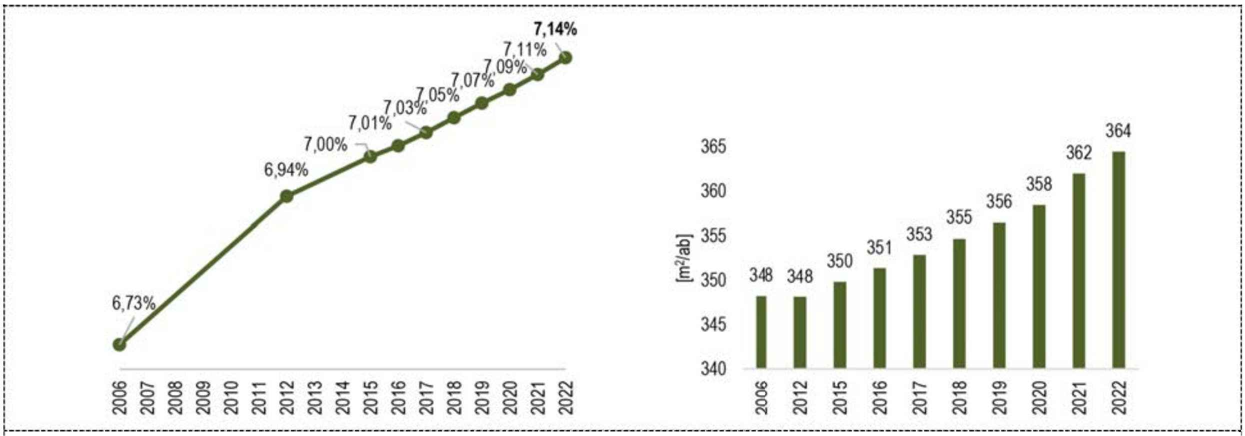

Figure 2. Left: Estimated consumed land (2006-2022), in percentage, in Italy. The 7,14% corresponds to 21.500 Km^2. Right: Land take, pro-capite, per year. Source [3] p.16.

The statistics clearly highlight how Europe (and in particular some of the States including Italy) is far away from reaching the ambitious objectives set by the EU for land redevelopment, proving that our economy and our development are still based on the unsustainable "conquest of land".

2. The vegetation of SuDS-Sustainable Drainage Systems: direct benefits to water cycle and side effects

Among the actions to improve the soil quality – like to enhance the carbon removals by LULUCF, to prioritize a circular use of land, to improve the soil biodiversity, to restore the sponge-like function of soils – the hierarchy in land planning is provided by EU Soil Strategy, in order of importance [1] p.9:

1. Avoid additional land take and sealing as much as possible;
2. Reuse land that is already taken or sealed;
3. Minimaze the use of healthy forests or fertile agricultural land, rather use land in less favorable condition;
4. Compensate with measures to minimize the loss of ecosystem services.

The mitigation and compensation measures explicitly include technologies and systems for infiltration, absoption and water storage, like green roofs, city gardens and urban greenery. The technologies capable of managing rainwater are many NbS-Nature-based Solutions and more specifically the sub-cathegory of SuDS-Sustainable Drainage Systems. The SuDS are a wide and very heterogeneous group of solutions which mimic the functions of natural soil in processing water, favoring water infiltration and accumulation to detriment of surface water run-off generated by impervious surfaces. The list of SuDS goes from the attenuation storage tanks ("most artificial", like concrete tanks, oversize pipes or other types of underground storage systems) to trees ("most natural"). Typically, SuDS provide multiply benefits [4] pp.19-27, like protecting the urbanized soil by flood risk, improving the quality of groundwater and surface water from polluted run-off, replenishing the groundwater level, reducing erosion, improving biodiversity, providing amenity and several others. The solely vegetation of SuDS – in green roofs, bioretention systems (rain gardens), filter stripes, vegetated channels and swale, vegetated pervious pavements, trees, in addition to the wider as wetlands and basins – provides (1) a set of benefits to water cycle, and also (2) further positive effects, the required ecosystem services mentioned by EU, as introduces below:

- the canopy is the first layer reached by the precipitation, it intercepts and retains a certain percentage of rain water, reducing the water rate to the soil/surface. The interception storage

capacity varies according to the canopy type, its dimension and, obviously, meteorologic factors [5] [6]. The intercepted precipitation by canopy is then evaporated to atmosphere;
- vegetation transpires part of the infiltrated water into the soil. It depends by the rough vegetation canopy, the availability of water in the soil (moisture), and the "evaporative demand" of the atmosphere [8] [9];
- the vegetation can treat the rain water, helping in reducing the contaminants, sediments and pollutants, from impervious surfaces and atmosphere, thanks to biological uptake [10] [11];
- the vegetation represents and supports the urban biodiversity [12] [13] [14] [15];
- the vegetation participates in reducing the Urban Heat Island effect, providing shadow and using solar energy for evapotranspiration, and improves the quality of air [16] [17] [18];
- plants qualifies the urban environment providing amenity and green spaces, encouraging outdoor activities spaces and sociality [19] [20] [21].

The SuDS that include vegetation therefore have an active and adaptive component towards the urban environment capable of bringing multiple direct benefits to the water cycle, as well as qualifying positive effects to urban enviroment.

3. The urban impervious surfaces: the problems to water cycle

The water cycle in cities is compromised by the impervious surfaces like roofs, streets, and paved open spaces. The constructed horizontal surfaces intercept and quickly deflect the rain water to urban drainage systems, de-functionalizing the soil (because impervious) of its function as a sponge capable of absorbing and filtering water [4]. The city land is extensively sealed for the roofing functions and road traffic need, including all means of transport, motorized and non-motorized, and pedestrians. The negative consequences from the impervious surfaces are many and are becoming severe due to the modification of the intense rain events, which more frequently are torrential and long lasting. Most of the rain water on impervious surfaces turns into surface run-off and, in combination with unfavorable circumstances, can cause:

- Floods and flash-floods:

a) Flooding from surface water: run-off is not removed quickly enough;
b) Sewer flooding: the flow rate exceeds the carrying capacity of urban drainage systems;
c) Flooding from receiving water bodies: excessive flow in a short time increases the flow of rivers, locally, at the hydrographic basin scale and in particular downstream;

- Erosion: rapid flow causes erosion, changing the shape of banks and carrying debris downstream;
- Water pollution: surface run-off, which has not crossed the ground, brings pollution into rivers, affecting the quality of the water;
- No aquifers feeding.

At the same time the network of draining system, so the sewer system, fails to cope with run-off si intense, because its "design flow" is undersized for the rainfall and the soil sealing now achieved. When rainfall is very intense and/or last too much time, the run-off is greater than the design flow. In this case the sewer system goes into crisis, it is unable to drain more water than it was designed for, and increasing the section of drainage is sometimes possible (in areas where the pipes were dimensioned for a less intense urbanization) but often not possible, due to physical constraints and, above all, the possible inefficiency in ordinary conditions. Rather than substituting the drainage systems with huge tunnels, the hydraulic risk could be mitigated by increasing the permeable areas and the soil retention capacity, i.e. solutions that mitigate meteoric run-off in urban areas with a more sustainable solutions, providing an alternative way to the rain, other than the sewer system.

4. Hydrologic parameter and rain events: the variability in performance

The performance of SuDS are various and described by several indicators, like permeability, water storage capacity, run-off coefficient, inflow coefficient and others. In this paper, the test for run-off coefficient calculation, through a rain chamber equipment, is described together with a variation of the test in order to explain some factors of the performance variability.

4.1. The objective of the experiment

The following experiment concerns the calculation of the run-off coefficient of an extensive green roof and also a procedural variation of the test which demonstrates how the hydrological response of the green roof can change for the same intensity and duration of rainfall.

The choice of the green roof, rather than another type of vegetated technology, is given by the fact that the green roof is a consolidated state-of-the-art technology, highly "engineered" in its layering, whose functioning is proven by mature international guidelines and standards; furthermore its hydrological performance is also classified and described in the calculation procedure.

Normally, the hydrological performance of the green roof is expressed by the run-off coefficient (C). The run-off coefficient is a dimensionless coefficient relating the amount of run-off to the amount of precipitation received. It is a larger value for areas with low infiltration and high run-off (pavement, steep gradient), and lower for permeable, well vegetated areas (forest, flat land). It is used to characterize the ability of a green roof to manage rainwater by accumulating rain in its layering. The run-off coefficient relates the amount of run-off to the rainfall received, therefore describing the run-off savings, in terms of percentage of volume.

It is important to underline that the run-off coefficient is an indicator used not only for green roofs, but also for other types of roofs, for paving and natural horizontal surfaces, which is why it lends itself well to comparisons between very different technologies.

In summary, the objectives of this experiment were:

- calculate the run-off coefficient of an extensive green roof;
- compare the hydrological response of the sample green roof as the sequence of rainfall events varies.

4.2. Methodology of the experiment

The run-off is calculated according to a methodology provided by the FLL Green Roof Guidelines [22] [23]. The larger values correspond to higher run-off and lower infiltration.

It is obtained applying to a green roof layering of 5 square meters, with no vegetation, a rain of r = 300 l/(s*ha), i.e. 27 l/m^2 in 15 minutes, after a water saturation and draining of twenty-four hours. The experiment is expected to be repeated three times, with all same input data, in order to fully saturate the substrate and to consolidate the final result.

The experiment tested an extensive green roof, implemented according to Italian standard, with 8 centimeters of mineral substrate. Considering the characteristics of the substrate, very mineral, the performance was expected to be very draining to the detriment of water storage capacity. The sample green roof was tested in a rain chamber, which was equipped to reproduce a controlled intensity of rain and to measure both the rain on the green roof and the run-off from the green roof.

The run-off coefficient has then been calculated as the following equation:

Run-off coefficient = *C* = water discharged in 15 min / rain volume in 15 min

After calculating the C coefficient, the test was repeated 2 more times with the same input data except for the duration of the inter-events in order to verify any differences in the hydrological response of the sample green roof.

4.3. Input data, output data and discussion

In Figure 3 the result from the first test is provided. The test provide the run-off coefficient C = 91/135 = 0.67

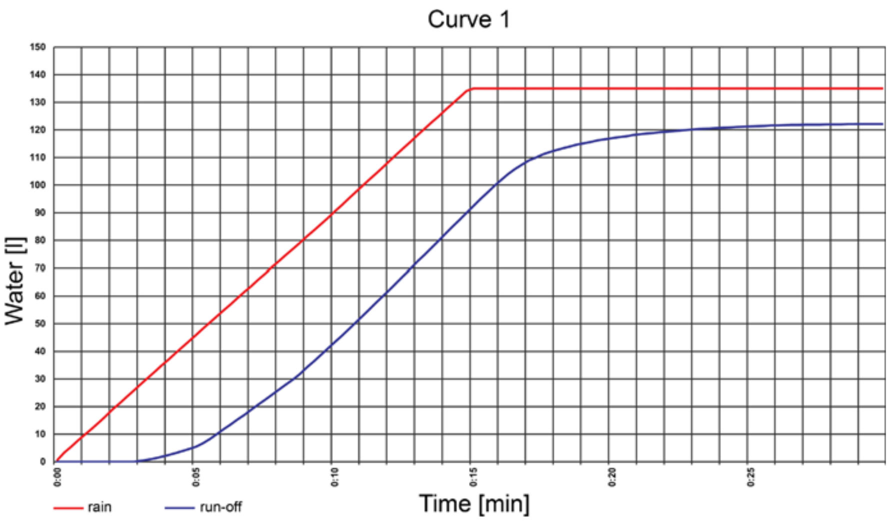

Figure 3. Test 1: the run-off was calculated according to the FLL standard, with a block-rain of 27 l/m^2 in 15 minutes, after an inter-event of 24 hours.

The two subsequent tests were conducted with the same rainfall value, i.e. a block rain of 9 mm in 15 minutes, but with a shorter inter-event duration: the second test was preceded by a 3-hour inter-event and the third test was preceded by a 1-hour inter-event.

The graphs in Figures 4 and 5 show the results, which are summarized in Table 2.

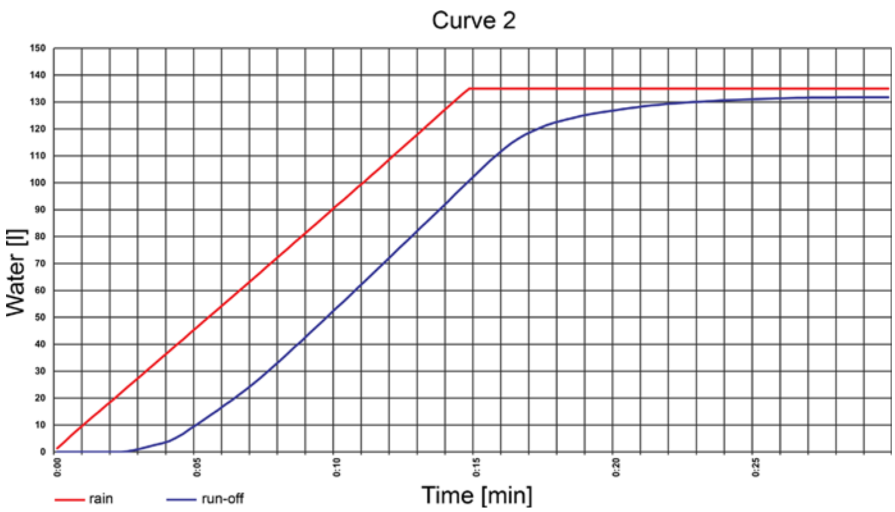

Figure 4. Test 2: run-off from a block-rain of 27 l/m^2 in 15 minutes, after an inter-event of 3 hours.

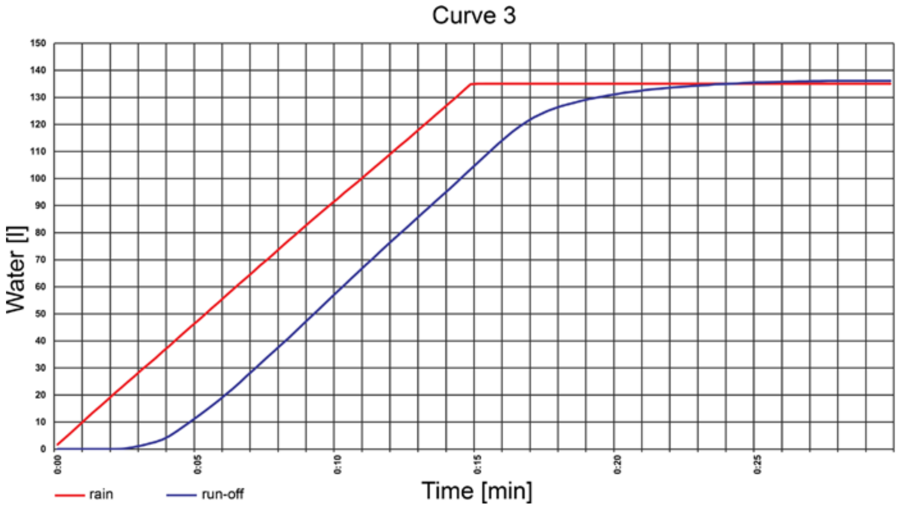

Figure 5. Test 3: run-off from a block-rain of 27 l/m^2 in 15 minutes, after an inter-event of 1 hour.

Table 2. Comparison of the run-off coefficient (C) from FLL Green Roofing Guidelines with the tested values carachterized by shorter inter-events

	FLL Green Roof Guidelines	Test 1 (repeated 3 times)	Test 2	Test 3
Substrate thickness [cm]	6-10 cm	8 cm	8 cm	8 cm
Inter-event [h]	**24 h**	**24 h**	**3 h**	**1 h**
C	0.5	0.67	-	-
IN block [l] ($Rain_{15\ min}$)	135.0			
OUT block [l] ($Run\text{-}off_{15\ min}$)	67.5	91.0	103.3	105.8
Accumulation [l] ($Run\text{-}off_{tot}$)	-	122.1	131.8	136.1

The obtained value from the Test 1 represents a quit draining extensive green roof, actually corresponding to expectations. The result run-off coefficient C = 0.67 is higher compared to the value provided by the FLL Green Roof Guidelines for extensive green roofs (with the same substrate depth) C = 0.5 (Table 2). The difference is determined by the characteristics of the substrate which is composed by mineral materials and not at all organic material.

The Ttests 2 and 3 do not provide a run-off coefficient, due to the different last of the inter-events, but provide comparable output data since the 3 tests were carried out with the same block rain (set by the C equation). Comparing the graphs and the data of table is possible to observe and to verify the out block in 15 minutes (the run-off volume at the end of the 15 minutes of intense rain) and the accumulation (the discharged volume to drainage system).

The graphs demontsrate that:

1. The curve of Test 1 is the lowest, in fact at the 15th minute the water delivered is 92.4 liters. Differently, the curves of tests 2 and 3 give 103.3 and 105.8 liters respectively. This means

that the longer the inter-event, the greater the water accumulation capacity becomes during the following events;

2. As a consequence of the point 1., just described, the total volume delivered (over 15 minutes, with a marked delay) is evidently lower in curve of Test 1, i.e. 122.1 liters, compared to curve of Test 2 (131.8 litres) and curve of Test 3 (136.1 liters);
3. In the curve of Test 1 the gravitational water (the delay in delivery) appears 3 minutes after the start of the rain event, while in curve of Test 2 after 2 minutes and 30 seconds and in curve of Test 3 after 2 minutes;
4. The slope of the three run-off curves is almost equal to each other and is also equal to the slope of the rainfall curve. This means that (in these cases) the intensity of the run-off peak corresponds to the intensity of the rain (intensity verified during the experiment);
5. The curve of Test 3 shows that the delivered water is even higher than the intercepted water (136.1 liters versus 135.0 liters). This could be determined by a not increasing permeability of the layering downwards.

5. Conclusion

The hydrological performance of drainage systems, capable of accumulating water, can be expressed with parameters like the run-off coefficient, the run-off volume, the peak attenuation, the run-off delay. At the same time the hydrological performance are closely linked to the rainfall regime, the intensity of events and the starting moisture conditions, which may significantly vary the performance. Moreover, the performance of vegetation rather than vegetated systems (such as green roofs, which are among the “most engineered” of the group of vegetated systems), in fact, are not included in the run-off coefficient calculation, missing, in this way, part of the performance.

This experiment demonstrates that the run-off coefficient is a parameter that indicates a hydrological performance given precise conditions of system saturation and rainfall. Varying the input data, even in a minimal way, the hydrologic response of the technology may change, potentially it can change quite a bit, that is in significant percentages. As demonstrated, following a succession of very intense and very close rainfalls, the green roof has a limited ability to reduce run-off volumes and the delay run-off peaks, while it has no ability to reduce run-off peaks. This happens because, when the layering has reached the maximum water accumulation capacity, it takes time for the substrate and the entire stratigraphy to partially restore their water storage capacity, which occurs thanks to the evaporation.

On the other hand, the calculation method of C suggests further thoughts, useful for understanding the value and performance of water retention. The C is calculated 24 hours after maximum water saturation, with a very high rainfall intensity. Considering this, the data obtained is representative of the reduction in run-off volumes (in the medium-long term); but, as demonstrated, the performance of the green roof can be better or worse than how much C expresses in relation to the local rainfall trend. The performance design of green roofs and green SuDS is linked to several circumstantial factors, including the characteristics of vegetation. As scientific licterature proves [24], in general, SuDS are systems and technologies that significantly improve the resilience of the built-up area, slowing down the urban water cycle and improving water quality, expecially when they are applied “in series”, as theorized by the design of “SuDS management train” [4] [25]: “this describes the use of a sequence of SuDS components that collectively provide the necessary processes to control the frequency of run-off, the flow rates and the volumes of run-off, and to reduce concentrations of contaminants to acceptable levels”, composing a sequence of solutions which may provide the hydrological performance of an urban area: to collect, to convey, to store and to treat run-off as it drains through the site [4].

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Peer Review Statement

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All papers published in this volume have been reviewed through processes administered by the Editors. Reviews were conducted by expert referees to the professional and scientific standards expected of a proceedings journal published by IOP Publishing.

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- **Number of submissions accepted:** 69
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- **Average number of reviews per paper:** 2
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Preface

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PREFACE

This **NEXTBUILT 2024** Conference Proceedings comprise the selected papers contributing to the 2024 **International Conference on Challenges for the NEXT generation BUILT Environment**, held in Bologna on two years basis, with the ambition to become a reference event to share and discuss drivers of change, barriers and solutions for shaping the future built environment considering the impact of Climate Change. The Conference is one of the main outcomes of the NEXTBUILT Observatory, whose main scope is to collect, analyse, and report information, research, and studies dealing with the most urgent and hot topics influencing the transformation directions in contemporary cities with a forward-looking perspective. The initiative is supported and fed by the research activity run at the Department of Architecture of the **University of Bologna** as well as by the constant transformative plans led by the City of Bologna.
NEXTBUILT 2024 was **held in Bologna on May 9th and 10th 2024**, with the chance to join the conference online for those who were not able to attend in person, under the overarching theme of **"a reflection on the future of the built environment within a context of resource scarcity or heavily influenced by climate change impacts, assuming a strong future oriented approach"**.
The conference was accordingly organized around four main topics:

- **Energy use and affordability in the built environment**
  Energy market global instability, progressive fossil fuel scarcity and related price fluctuations call for new approaches which combine technical and socio-economical interventions to possibly ensure fair and sustainable access to adequate energy services for all. Nonetheless, energy poverty rates are rising globally without effective and future-oriented solutions being promptly drafted to mitigate the impact of this issue. Besides, it strongly emerges the need to shift to cleaner energy sources while possibly reducing the demand intensity and impacts of the building sector. It is largely agreed within the scientific community that structural changes should be made to reduce the roots of energy challenges in the built environment, but how can policymakers, planners, and designers innovate the retrofitting market remains an open issue despite it is acknowledged to be the most urgent and promising field of action.
- **Water scarcity and cities response capacity to extreme events**
  In recent years, many countries worldwide have suffered the effects of climate change, especially in relation to water. From devastating floods to severe droughts, water scarcity or abundance is increasingly affecting life in urban environments, involving over half of the world population according to IPCC projections. On the one hand, conventional water management solutions in cities have been proven inadequate to address intense rain events and water needs; on the other, progressive climate topicalization is posing a risk to ensuring adequate access to fresh water. Cities are actively seeking effective solutions to reduce the flood risk and save water for use (including, among others, water-efficient buildings and construction processes), but more integrated and interdisciplinary approaches are not well-established yet. More integrated and systemic solutions to let cities and buildings be reshaped to mitigate and/or adapt to increasingly severe water-related issues are needed.
- **New paradigms in buildings and components expected lifetime**
  Heavy depletion of natural resources and the need to achieve carbon neutrality targets are strongly encouraging policymakers, researchers, and designers to change their perspectives on life-cycle impacts, durability and service life of buildings and components. However, the majority of current interventions in the building sector are still focused on lowering the operational energy demand while paying less attention to embodied energy and carbon as well as to the end-of-life stage. The increasingly fast evolution of needs and requirements is calling to strategically rethink the expected lifespan of buildings and to carefully consider the use of materials and design choices within a circular-based perspective, not only at the local level but also at a larger scale. This seeks for innovative measures, methodologies, procedures, and tools to facilitate and support a mind shift and a market transition.
- **Tools and means to go beyond the climate neutral transition**
  Current policies, measures and tools to achieve sustainable development and carbon neutrality have largely proven inadequate and limited. Many of them can only deal with short-term visions and effects of planning procedures, design, and building processes. However, given the unpredictability of the future in the long run, effective and forward-thinking measures must be taken now. Can the carbon neutrality challenge, which is now assumed to be a target, be turned into a useful means to that end?

The main issue remains to plan, design, and build for future changes that will almost certainly imply progressive resource scarcity (physical and non-physical) along with other challenges yet to come.

The breadth and urgency of the topics allowed to collect several insightful and novel contributions spanning current trends and innovations, empirical findings and concrete applications in the fields of science, industry, policy, and governance. However, the main detected barriers to concrete progress deal with the lack of systemic approaches and long-term visions to go beyond the urgency of the present time. In the background, the need for more balanced and environmentally driven economic models remains a turning point yet to come.

The conference stimulated a vivid dialogue between the invited keynote speakers and the participants in both the plenary and parallel sessions. NEXTBUILT 2024 had the privilege to host:

- **Brenda Boardman**, from the Environmental Change Institute, University of Oxford, whose studies since the early 90s contributed to providing the definition of Energy Poverty still in use globally. Her key lecture titled ***Energy prices, energy efficiency and equity*** considered the competing needs of the poorest households and climate change, both today and into the future.
- **Louisa Bowles**, Partner and Head of Sustainability at Hawkins\Brown, who has led several multi-disciplinary projects and is an active contributor to many industry organisations working to improve environmental performance. Her key lecture titled ***Circular economy, buildings as material banks*** stimulated a reflection on a mind shift in the way we use and understand the service life of materials in contemporary architecture.
- **Paolo Negro**, Research officer at the Joint Research Centre of the European Commission, with a long experience in research activity and scientific policy advising, whose key lecture titled ***A strategy for the holistic rehabilitation of buildings and the new European Bauhaus*** outlined the main challenges at EU level with reference to multiple actions under the umbrella of the green deal.
- **Elisabete Teixeira**, from the University of Minho where she serves as a dedicated Researcher at ISISE (Institute for Sustainability and Innovation in Structural Engineering). Her key lecture titled ***Synergizing nature-based solutions for water resilience and urban infrastructure protection*** highlighted the importance of more coordinated actions and systemic approaches to put in place more effective mitigative strategies.

The conference included eleven parallel sessions organised during the two days to expand the dialogue opportunities and to let all the participants from seventeen countries exchange ideas and proposals for facilitating synergies and future cooperation opportunities. A NEXT TALK inviting three architectural design firms, NET Engineering, Pier Currà Architettura, Open Project, was also held to bridge the gap between academic research and the professional market enlarging the horizon of research to very practical implications. As the necessary transition of our built and urban environments is becoming more urgent NEXT BUILT tried to attract the attention of the key involved stakeholders to stimulate collaboration and partnerships while laying the foundations for meaningfully shaping policy, practice, and capacity-building programs.

This Proceedings collect the main individual contributions organized according to the four main topics that underpin the conference's scientific program. Each submission underwent a two-round (abstract and full paper) double-blind peer-review process. The NEXTBUILT Scientific Committee and the Editors carefully handled the process to ensure only those meeting the necessary scientific standards were presented at the conference and included in these
proceedings.

Editors
Jacopo Gaspari
Licia Felicioni
Lia Marchi
Ernesto Antonini

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Julie Železná | Senior researcher | University Centre for Energy Efficient Buildings – Bustehrad, Czech Republic

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Ernesto Antonini, Andrea Boeri, Jacopo Gaspari, Danila Longo, Beatrice Turillazzi

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