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Introduction

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Throughout history, humans have reshaped the environment to meet their needs, often in ways that appear confrontational. Forests are cleared to make way for agriculture and expanding cities, hills are excavated for raw materials, rivers are diverted, coastlines are reclaimed, and landscapes are reconstructed to suit human ambition. The 20th and 21st centuries, in particular, have been marked by an unshakable faith in technology, empowering humans to dominate nature, remold landscapes, and impose control over natural forces. Nature, once revered and feared, has been increasingly perceived as something to be tamed –like a domesticated animal that must submit to human will– while technology has served as the primary instrument of this dominance.

However, this confidence in human supremacy over nature is frequently tested, often shattered, by extreme environmental events. The devastating floods in Thessaly –first after Ianos storm in 2020 and later after Daniel and Elias storms in 2023– serve as stark reminders of nature’s unpredictable power. These disasters challenge conventional urban planning approaches, raising urgent questions: How can we rethink the relationship between nature and the built environment, not through force and rigid control but with understanding and empathy? How can we acknowledge the dynamism and resilience of natural forces –particularly water– and shift from an adversarial stance to one of adaptation and coexistence?

More than a century ago, during the emergence of modern urban planning, Patrick Geddes, a visionary philosopher, biologist, sociologist, and urban planner, championed the idea that urban design must be rooted in the specific context of a place –its landscape, geography, and inherent potential– rather than an abstract, imposed vision dictated by the authority of planners. A hundred years later, this principle remains

In these cases, water is considered as matter, as a resource, or as part of a reserve strategy, or urban storm water regulation, or fire mitigation.

Regarding specific study cases, I mention the work within the framework of RedSur as an inter- university network for academic exchange, at the undergraduate, graduate and research fields, working on emerging issues in vulnerable contexts. It is worth mentioning that the University of Thessaly is part of RedSur, and numerous workshops and cooperation in undergraduate and graduate programs have been carried out.

The present Erasmus Workshop, BIP, clearly focused on the questions and concerns expressed here, starting from adversities and disasters, which unmask unsolved problems, counterproductive actions, negative interactions between territory, city, infrastructure, production, housing, among other variables to be considered; highlighting the need to review the values on which the readings and practices in the urban territorial context have been based, calling for operational reflections that promote new strategies on the consideration of “hybrid landscapes” as an instrument for new conciliations between nature and artifice, contributing to reestablish damaged balances, mitigate the consequences of catastrophes and possibly reduce the recurrence of the episodes.

The experience of the different disaster scenarios and their particular problems – Karla Lake, Larissa, Volos, Trikala, Mikro – together with the process proposed, allowed the full awareness of the pressing needs, revealing new conciliations between nature and artifice.

Perhaps the complexity lies in the sound understanding of the different landscapes be them urban, human, cultural, sensorial…

Landscape as integrity.

…And, in the face of the challenges of the contemporary global panorama, we need to rethink, seeking better socio-environmental balances… to contribute to Re-Inhabiting a World that already exists, but that has become increasingly dysfunctional.

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Monica Bertolino and Carlos Barrado have founded the Bertolino - Barrado Architecture firm, which focuses on architectural, urban and landscape design. The firm has received numerous awards and notable mentions, among them: 2022 Soy Arquitecta- Project Award; 2012 Konex Award; 2011 ARQ Clarín prize; nomination for the 2011 and 2013 Marcus Prize in Milwaukee; 2010 VII Iberoamerican Biennial Award for Architecture and Urbanism; 2002 Quito PanAmerican Biennial, International Honorable Mention; the 2000 Vitruvio Award, among others. Projects by Bertolino - Barrado have been published in national and international books, magazines, and tv documentaries.

Sustainable Urban Drainage Systems: a comprehensive approach to urban flood risk management in Padova

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Introduction

Urban flooding presents a significant challenge, particularly in cities facing intense and unpredictable precipitation events. This paper draws extensively from the comprehensive strategies and principles outlined in the book “Linee Guida per il Drenaggio Urbano Sostenibile”[1] and developed by Iuav University of Venice in collaboration with the Municipality of Padova and the Environment Office as a continuation of the activities under the Sustainable Energy and Climate Action Plan (SECAP). The focus is on the city of Padova’s approach to mitigating urban flooding. By implementing Sustainable Urban Drainage Systems (SUDS) and integrating these into urban planning and infrastructure design, Padova aims to strengthen its resilience against extreme weather events, improve water management, and contribute to the overall sustainability of the urban environment. The journey began in the past decade when, in 2016, Padova became one of the first Italian municipalities to draft guidelines for the adaptation plan. This effort was followed by the approval of the SECAP, in which the Municipality laid the groundwork for the first coordinated effort among its sectors toward climate action. This trajectory has been consistently upheld by the Municipality, which has further supported it with additional training and awareness initiatives, including the 2021 adaptation guidelines and the masterplan for the adaptation of the industrial area, which is set to be delivered by the end of 2024. The present paper analyzes, summarizes, and presents the innovative principles that have enabled the Municipality of Padova to emerge as a leader among Italian municipalities in studying and experimenting with technologies designed to adapt the urban environments from the damages caused by intense rainfall.

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[1] V. Negretto, E. Giacomello, N. Romanato, and B. Gava, *Linee guida per il drenaggio urbano sostenibile* (CORILA editore, 2022).

Urban Flooding and Climate Change

Urbanization has led to significant changes in land use, with increased impermeable surfaces exacerbating the challenges of managing stormwater runoff. In Padova, as in many other cities, the traditional drainage systems are often overwhelmed during intense rainfall events, leading to urban flooding[2].

The response of urban environments and management systems is not uniform and homogeneous. This difference can be amplified by localized, temporary factors, such as blocked drains due to poor maintenance or malfunctioning mechanical systems. Other local factors related to the disposal network can influence the response of certain areas, such as undersized pipelines or inadequately drained depressed zones.

The increasing frequency and intensity of rainfall events, often referred to as "cloudbursts," pose a growing risk to urban areas. Padova has not been immune to these phenomena, with several instances of flooding recorded in recent years. These events highlight the vulnerability of urban infrastructure to climate change and underscore the need for adaptive measures. The traditional urban drainage systems, designed to manage moderate and infrequent rainfall, are no longer sufficient to cope with the volume and speed of water generated during intense storms.

New Perspectives for Sustainable Urban Drainage

The impermeabilization of urban soils has significant impacts on the hydrological cycle, complicating the management of intense precipitation events. The primary effects include increased surface runoff, due to reduced infiltration and evapotranspiration capacities, and shortened times of concentration. As a result, compared to permeable soils, impermeable surfaces generate a larger quantity of water that must be managed within a shorter time frame.

The context of the different Italian approaches to hydraulic management is dealt with in the publication by Pasi et al. [3] comparing the main Italian approaches with Anglo-Saxon ones. This study shows that in Veneto, as in some other Italian regions, the approach to compensating for the impacts of urbanization on the water cycle remains strongly tied to the principle of hydraulic invariance. This principle dictates that any transformation of land use should not contribute to increasing the peak flow of the receiving water body. Hydraulic invariance requires the quantification and provision of a detention volume to compensate for the effects of urbanization, thereby placing the burden of the resulting impermeabilization on the entity proposing the transformation.

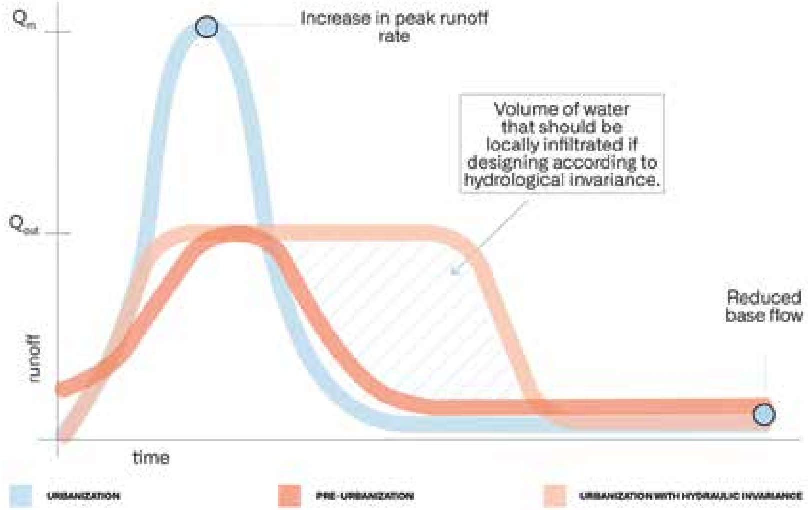

Fig. 1

Figure 1
Conceptual schematic representing runoff (on the vertical axis) in relation to time (on the horizontal axis). The response to the same type of rainfall event is depicted for the same area under three different conditions. In pre-urbanization conditions, the area generates a lower total runoff because part of it is infiltrated, and the peak outflow rate is relatively low. In urbanized conditions, the area responds quickly to the rainfall event, resulting in a significantly higher peak outflow rate and a greater total runoff due to the reduction of soil available for infiltration caused by urbanization. In urbanized conditions following the principle of hydraulic invariance, the peak outflow rate is artificially maintained at the pre-urbanization level by storing excess volumes in basins, which are then gradually released, leading to a total volume that is higher than the pre-urbanized state and equal to that of the urbanized state. Source: Negretto et al. 2022.

However, the establishment of such detention volumes is not intended to retain runoff locally but rather to maintain the formation of peak flows at the basin scale. The objective is to artificially maintain the maximum outflow from the urbanized area within the limits of pre-urbanization conditions. Hydraulic invariance, therefore, concerns the maximum discharge rate that can flow downstream in a given time, not the total volume of runoff. It is evident that the urbanization of an agricultural field, for example, while adhering to the principle of hydraulic invariance, will not eliminate impacts on the hydrological cycle; only the peak discharge rate leaving the urbanized area will remain "unvaried".

Pasi et al. (2019) highlights that other impacts on the hydrological cycle must also be considered, such as the total runoff volume exiting the transformed area. In some Italian contexts, such as the Lombardia Region, the concept of invariance has been extended to include hydrological invariance. This principle asserts that the volumes discharged into the receiving water bodies (sewers, rivers, etc.) from transformed areas should not exceed those existing before the transformation. Therefore, the increased runoff caused by new development and the resulting impermeabilization must be managed locally through infiltration and reuse. [fig. 1]

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[2] ARPAV Veneto, *Intense Precipitation Events in Padua* (2022), Interreg Response.

[3] R. Pasi, V. Negretto, and F. Musco, *Diversi approcci al drenaggio urbano sostenibile: un confronto tra il contesto normativo inglese e quello italiano* (Franco Angeli, 2019), Archivio Studi Urbani e Regionali.

Given the frequent flooding recorded in Padova and in many other cities, it would be prudent to move beyond the approach of merely maintaining the runoff generated by urban soils during each rainfall event, whether in terms of flow rate (hydraulic) or volume (hydrological). The management of runoff becomes problematic with frequent intense rainfall events; therefore, an approach that aims for “variance” of the current hydraulic and hydrological imbalance through widespread and systematic interventions would be more appropriate. This would improve the territories’ responses to the stresses caused by intense rainfall while simultaneously pursuing benefits for ordinary rainfall as well.

A Hierarchy of Priorities for Intervention

The hierarchy of priorities guides the selection of techniques for designing interventions, favoring principles that provide greater benefits at both local and basin scales. Higher-priority principles are preferred as they yield more significant outcomes, even during minor rainfall events, with subsequent runoff managed by lower-priority principles. If implementing a higher-priority principle is not feasible, lower levels can be considered. The hierarchy of principles presented here is inspired by the Anglo-Saxon approach detailed by Woods-Ballard[4] and further analyzed in Pasi et al. The framework based on principles is extensively explored in Negretto[5] where its connections to various indicators are also discussed. The following summary distills the core logic of this approach, offering a concise explanation tailored for policymakers.

This approach is applied with a focus on water quality, as rainwater often collects pollutants from surfaces. These contaminants, particularly concentrated in the “first flush”, necessitate preemptive assessment and filtration measures. Treating polluted water close to its source is recommended, as it simplifies isolation and management. Various first-flush treatment devices, including sustainable techniques, are available and provide broader benefits than conventional first-flush tanks.[fig. 2]

It is advisable to treat this potentially polluted water as close as possible to the source of contamination since it is easier to isolate potentially polluting areas and manage treatment points. Various devices exist for treating first flush water, including some of the sustainable techniques listed in the following chapter, which offer a broader range of benefits than the widely used first flush tanks.

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[4] B. Woods-Ballard, S. Wilson, H. Udele-Clark, S. Illman, R. Ashley, and R. Kellagher, *The SuDS Manual* (Construction Industry Research & Information Association, 2015), Report C753, 2nd ed.

[5] V. Negretto, “Systemic Approaches and Principles for Urban Stormwater Management,” in *Climate Change Adaptation, Flood Risks, and Beyond. State of Play in the Science-Policy-Action Nexus*, ed. M. Granceri, F. Musco, and F. Magni (Springer, 2024), Planning for Climate Cities series.

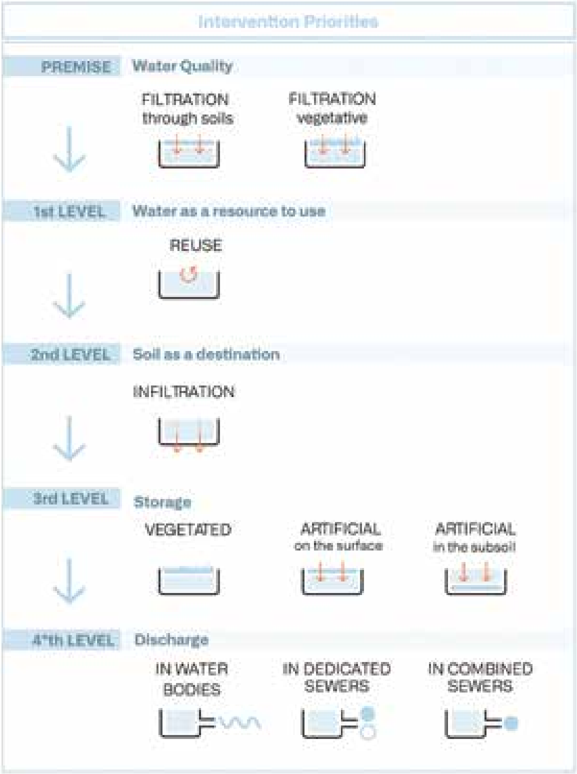

Fig. 2

Figure 2
The diagram presents a hierarchy of urban runoff management strategies, prioritizing interventions to ensure water quality. The top priority is water reuse, followed by soil infiltration to mimic natural processes. The next level involves temporary storage, using vegetated areas or artificial solutions. The least preferred option is discharging runoff into water bodies or sewers, reserved for situations where other methods are not viable. The hierarchy aims to promote sustainability and minimize environmental impact. Source: Negretto et al. 2022.

The primary priority in the hierarchy is on-site water reuse, which reduces runoff and future water demand. This principle is crucial as it minimizes the need to manage large volumes of water, particularly during intense rainfall. Reuse applications vary, commonly involving irrigation and non-potable uses. However, to effectively handle excess water during major events, reuse must be combined with lower-priority principles.

Directing runoff to the soil is the next priority, as it promotes infiltration, mimicking natural processes and supporting vegetation. This approach reduces runoff and can be implemented through appropriate surface design. By adopting these techniques, it is possible to enhance hydrological stability and retain water locally.

Runoff attenuation, the third priority, involves temporarily storing stormwater to reduce outflow rates. Although this principle offers fewer benefits, it is useful for managing intense events, often in conjunction with infiltration or reuse. The most sustainable attenuation areas are vegetated, followed by surface and then underground structures.

The final priority is direct discharge into receiving bodies, which should be employed only when other options are unfeasible, and in minimal quantities. Discharge into water bodies is preferred over sewer systems, with combined sewers being the least desirable option.

Implementation of SUDS in Padova: Savelli Square as a case study operative test

The design of SUDS must be evaluated based on the availability of suitable spaces, surfaces, and locations, considering both the attractiveness and effectiveness of the installation. Open spaces form the resilient framework of the built city and can serve multiple functions. Rethinking the design of future interventions can allow the adaptation of the existing city while simultaneously improving the quality of public space. In this classification, particular importance has been given to the system of open spaces and communication routes, but these techniques can also be adopted in other contexts.

The Savelli Square SUDS project aims to significantly reduce climate risks, both in terms of hydraulic impacts and the urban heat island effect, in an area that encompasses approximately 200 business offices in the tertiary sector. The intervention involves the use of stormwater collection and storage systems that reduce the hydraulic load on the urban sewer network. The intervention, which was funded with 829.000 euros by the Ministry of the Environment, transformed what was once a large asphalt area devoid of greenery into a square that still maintains parking spaces serving the existing businesses. However, the area now features permeable paving instead of impermeable asphalt, along with pedestrian and cycling paths, new urban furniture, trees, greenery, and charging stations for electric vehicles. The square itself encompasses 6,800 square meters, with 2,000 square meters dedicated to a grassland area designed for high rainwater absorption. The remaining 4,800 square meters, consisting of roads and parking areas, are paved with a special light-colored, highly permeable aggregate. This pavement technology not only reduces the square's impermeable surface area but also minimizes solar heat absorption, leading to a cooler environment.

The parking facilities within the square, designed to serve local businesses, include a total of 114 spaces, with 53 designated as paid parking, 59 as free spaces (including 5 reserved for disabled individuals), and infrastructure in place for the installation of 16 electric vehicle charging stations. These considerations underscore the square's role in supporting both sustainable transportation and accessibility. From an ecological perspective, the square integrates significant green infrastructure. A total of 52 trees – holm oaks, linden trees, hornbeams, and tulip trees – along with approximately 300 herbaceous plants, have been strategically planted to mitigate the urban heat island effect. Recent research highlights that in urban areas devoid of vegetation, temperatures can be up to five degrees Celsius higher compared to other city neighborhoods with extensive greenery. The introduction of this vegetation is expected to significantly reduce ambient temperatures within the square and its surrounding areas, contributing to improved microclimatic conditions.

The design documents report that for a 10 millimeters rainfall event or 10 liters per square meter, the hydrological benefit for the entire square results in 68000 liters of water being absorbed by the soil rather than contributing to surface runoff. This absorption process not only alleviates the burden on stormwater drainage systems but also supports groundwater recharge, thereby enhancing the local hydrological cycle.

During the planning of Savelli Square, several specific SUDS techniques were implemented that fully adhere to the previously outlined intervention principles of filtration, reuse, infiltration, storage, and discharge. Permeable pavements were utilized to allow water to infiltrate through the surface, effectively filtering runoff and promoting natural groundwater recharge. Rainwater harvesting systems were incorporated to capture and store rainwater, facilitating its reuse and thereby reducing both the demand on potable water supplies and the overall volume of runoff. Additionally, vegetated swales and bioretention areas were established to provide further filtration of stormwater, remove pollutants, and enhance infiltration into the ground. Collectively, these solutions not only address immediate water management needs but also contribute to sustainable urban climate adaptation by sequentially applying the principles of filtration (1), reuse (2), infiltration (3), storage (4), and responsible discharge (5). [fig. 3]

Fig. 3

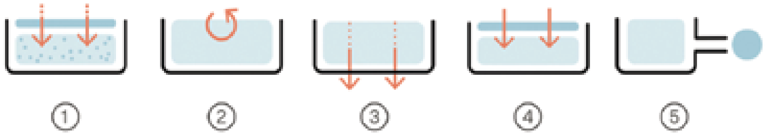

Figure 3
Savelli Square's intervention principles applied to the case study test.

Fig. 4

Fig. 5

Figure 4
Permeable pedestrian pathway and raingardens with trees within, designed to receive, absorb, and infiltrate rainwater volumes. Source: PadovaOggi.it

Figure 5
Drone aerial view of the Savelli Square. Source: PadovaOggi.it

Conclusion

Padova's approach to urban drainage represents a forward-thinking response to the challenges posed by climate change and urbanization. By adopting SUDS, the city not only addresses the immediate risks of urban flooding but also contributes to broader environmental goals. SUDS, indeed, respond to both hydraulic and hydrogeologic invariance approaches. Adopting both these management principles as guides for compensation gives soils an active role in both mitigating flooding and supporting all phases of the hydrological cycle. The positive effects also include increased soil infiltration, greater evapotranspiration benefiting the microclimate and air quality, and the potential reuse of water as a resource. Incorporating this consideration into the design of urban drainage systems enhances their effectiveness even in the face of frequent precipitation, providing tangible benefits in everyday situations. The integration of SUDS into urban planning demonstrates the potential for cities to evolve towards more sustainable and resilient futures. Continued investment in these systems, coupled with ongoing monitoring and adaptation, will be essential as climate patterns continue to change.

Nicola Romanato is an urban planner and researcher specializing in Planning and Policy for Cities, Environment, and Landscape, having graduated with honors from Università Iuav di Venezia. His career is marked by a strong commitment to urban resilience and climate adaptation strategies, as demonstrated by his recent work at the Planning and Climate Change LAB at Iuav, where he developed innovative solutions for managing the impacts of intense rainfall in urban settings and analyzed climate vulnerability across various scales. Currently, Nicola is engaged in a research project at Università Iuav di Venezia under the Interconnected Nord-Est Innovation Ecosystem (iNEST), focusing on creating a digital twin model for maritime and spatial planning. This project aims to promote urban sustainability by integrating land-sea mobility dynamics and fostering sustainable development along the Alto Adriatico coast.

Vittore Negretto, Ph.D. in Architecture, City, and Design from Università Iuav di Venezia is an Architect and Urban Planner. He is the research manager and adjunct professor in urban planning and climate change adaptation at Iuav.
His research focuses on understanding complex urban systems to guide strategic planning and develop innovative design solutions for climate change adaptation, risk reduction and sustainability. He is a consultant for local authorities and private companies in developing climate change resilience and adaptation plans, sustainable urban drainage systems and sustainable regeneration of urban areas.
He is currently a Research Associate at Fondazione Eni Enrico Mattei (FEEM), member of the Internation Panel for Adaptation Metrics (IPAM), and designated expert for Italy at UNFCCC.