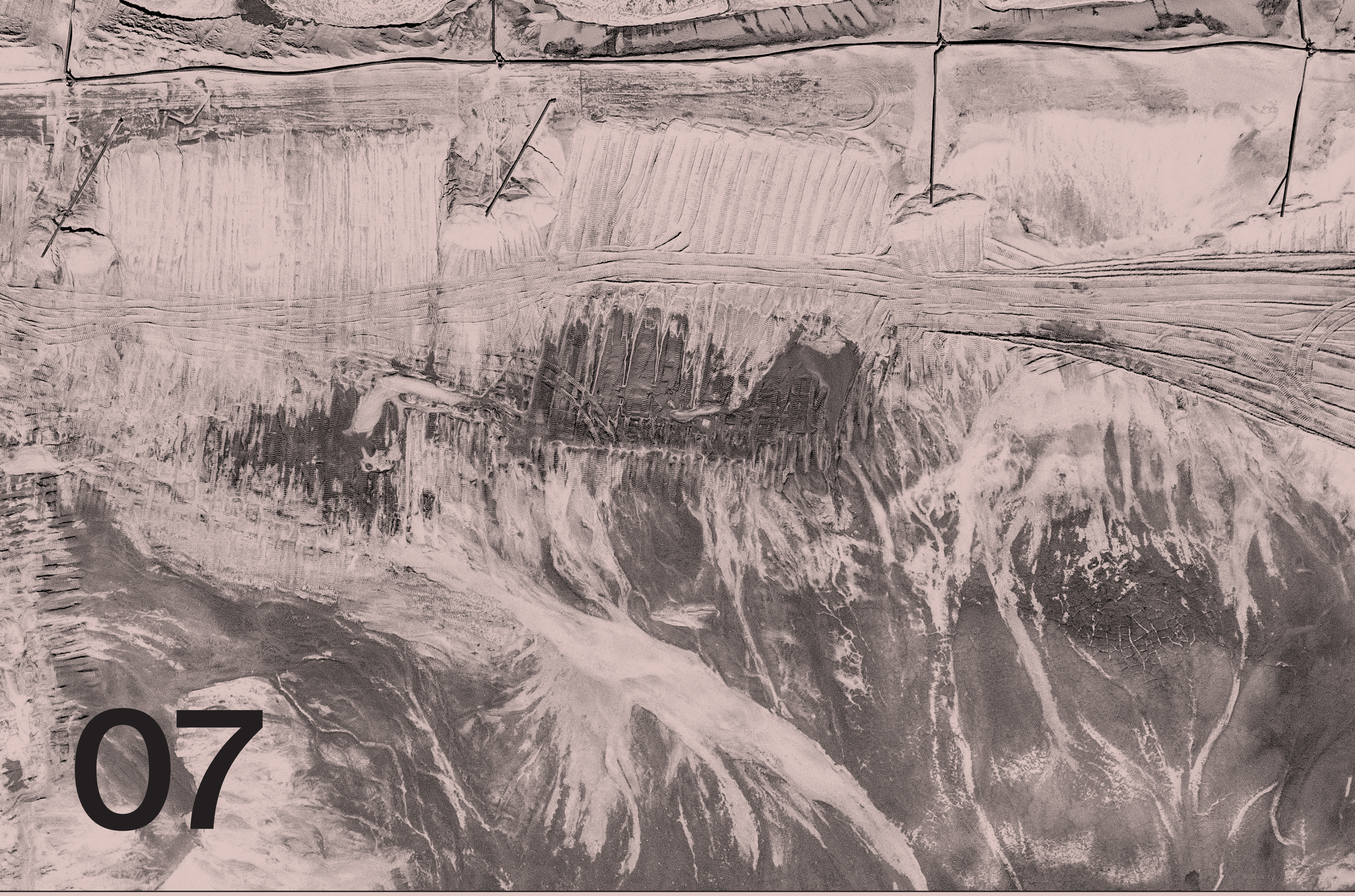

07

Infrastrutture

A CURA DI MARCO RANZATO E ALESSANDRO SGOBBO

ATTI DELLA XXVI CONFERENZA NAZIONALE SIU - SOCIETÀ ITALIANA DEGLI URBANISTI
NUOVE ECOLOGIE TERRITORIALI. COABITARE MONDI CHE CAMBIANO
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Modeling approaches in spatial planning for city regeneration with nature-based solutions

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Abstract
Current performance-based planning approaches and modeling can represent a valuable tool for the enhancement of nature-based solutions in city regeneration. Model simulations can be used in ex-ante design/plan evaluations but an effective use in operational urban planning is still missing. Urban planning with NBS is multidimensional and multi-objective in scope. Still, most studies related to NBS, tend to reduce their assessment to single issues and specific aspects the urban system deals with, often disregarding the complexity of impacts and trade-offs. Functional and spatial modeling approaches can better allow NBS complexity to be investigated at different temporal and spatial scales. This study examines existing modeling tools to explore the potential application in the urban planning practice and the set-up of spatial decision support systems. Comparative criteria are proposed to organize and evaluate information from the collected data and examples. To advance the knowledge of the NBS modeling tools and their suitability for the spatial planning processes and practices, criticalities and potentialities of models with regard to the planning context, the model characteristics, temporal and spatial scales, data resolution, and case studies implementation are investigated.
The models' applicability to capture and evaluate the spatial complexity and geographic diversity of the benefits produced by different NBS is discussed, and further recommendations for considering NBS modeling integration into the planning process to make the just decision on urban transformations are provided.

Parole chiave: spatial planning, green infrastructure, scenarios

1 | Nature-based Solutions and modeling in spatial planning

Understanding the relationship between urban form (e.g. density and building type), network infrastructure (e.g. drainage systems), and unbuilt spaces (e.g. green areas) is essential to making well-informed decisions about the placement of new and adaptation of existing land uses. For instance, cities are increasingly adopting Nature-Based Solutions (NBS) to address multiple societal challenges and urban regeneration effectively. However, inappropriate spatial planning and siting of NBS not only limit their functionality but can also lead to other issues such as ineffective resource use and environmental injustice (Sarabi et al., 2022).

Importantly, planners need support in the analysis and selection of suitable and effective NBS solutions looking together at different types of urban issues and spatially identifying the benefits these solutions can generate. In particular, reducing flooding and excess urban heat, and protecting populations from the consequences of extreme rain events and temperatures is one of the 21st century's key resilience and sustainability challenges for urban areas experiencing the effects of global warming (Majidi et al., 2019; Word Bank, 2022). Thus, NBS are particularly explored by the scientific literature to foster climate change adaptation, considering primarily their regulating benefits of increasing water retention and infiltration, reducing stormwater runoff, and reducing air temperature through shading and evapotranspiration (Cortinovis et al., 2022). Consequently, the quantification of the hydrological performance of NBS as well as their ability to improve the urban micro-climate based on physical properties and climate conditions is crucial. As it is the conceptualization of NBS in terms of their relevant planning aspects.

Models are proven to address city complexity and aid stakeholders in the challenging process of exploring theoretically possible scenarios (Abou Jaoude et al., 2022), and existing modeling tools (MTs) are increasingly used to aid the design and selection of NBS technologies, geometries, and configurations and to acquire a deeper knowledge of the processes underlying NBS planning and design (Pons et al., 2023).

However, on the one hand, past approaches to spatial and urban analyses, land use categorizations, zoning, and reference spatial units were traditionally used to support planning and design processes at the urban scale without analyzing or interpreting the physical spaces by combining multiple bio-physical perspectives (hydrological, hydraulic, energy, ecological and so on).

On the other hand, existing tools mostly address the modeling and communicating of the opportunities and performances of the urban system (including green technologies) based on analyses of biophysical processes (e.g., water balance models and hydrological/hydraulic models; energy models), rarely based on other aspects pertinent to spatial strategies and urban form.

As a result of both previous evidence, There are still gaps and barriers to wider uptake of such tools by cities and local authorities, which hinders their contribution to mainstream NBS projects at a local level. This is although many open-source or licensed tools and databases have been developed to guide the implementation of NBS measures aiming to create more resilient and sustainable urban areas, following the implementation of various European-funded research and innovation NBS projects. (Voskamp et al., 2021). Spatial planning still struggles to incorporate holistic scientific-disciplinary inputs into the processes of strategy analysis and evaluation, and land design control and has designed urban transformations that are unresponsive to urgent issues of risk mitigation and adaptation, ecologically oriented regeneration, equity of spatial planning outcomes, etc. At the same time, the "planning side" of urban water and energy management has remained underexposed since urban areas are faced with highly complex planning problems that go beyond conventional infrastructure engineering (Kuller et al., 2017).

To fully capitalize on the potential of NBS in spatial planning, the evidence of the effectiveness of NBS has to be diffused among policymakers, city planners, and inhabitants of many cities. Moreover, the analysis and selection of the most appropriate and effective planning solutions to different types of urban issues need to be more accessible. Thus, MTs should be carefully analyzed, and selected to integrate the spatial dimension of NBS in the planning process and to test and validate scenarios for case studies.

Depending on the typology of the urban issue focused, one or more models can be used for evaluating the potential contribution of different NBS to outdoor thermal comfort, urban energy consumption, and surface runoff regulation.

As a consequence, spatial and planning decision support systems (SP-DSS) can be usefully informed once modeling tools for NBS are selected based on a reasoned comparison, including factors of suitability to address specific challenges in cities, specific needs of end-users, and local contexts, easiness of applicability in spatial planning.

This paper overviews the existing modeling tools for NBS in cities to address flooding and heat extremes in urban areas and frames sets of comparative criteria to support a proper MTs selection for designing a comprehensive SP-DSS.

2 | Review of modeling tools

2.1 | Tools Collection

To examine the potentialities and shortcomings of NBS modeling tools that can be used to feed the SDSS for NBS uptake, the first step was to overview relevant NBS modeling tools. NBS are here understood as Solutions that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social, and economic benefits, and help build resilience (EC), referring mainly to green-blue infrastructure to address heat and flood risks as well as high-quality regeneration opportunities.

Modeling tools were identified by the authors based on their knowledge and expertise, and additional desk research.

The latter entailed a combination of reviewing the websites from EU-granted projects related to cities dealing with NBSs, ecosystem services (ESs), green infrastructure, urban resilience, and climate change and reviewing peer-reviewed scientific journals, reports, and grey literature. The search was implemented through Google Search, Google Scholar, and Scopus between January and April 2024.
After being slightly refined according to the research questions and objectives, the search resulted in a set of relevant modeling tools.
The tools were further compared only if adhered to the following conditions:
1. the modeling tool is understood to be a software package with a user interface or spreadsheet for NBS performance/benefits simulation. This means that the term 'modeling tool" goes beyond the term 'model' and may include several models and model choices (mathematical) (Pons et al., 2023).
2. the tool can be used to support NBS uptake in the urban environment (directly or indirectly allows for NBS performance/benefits simulation).
3. The tool's subject scope includes urban issues related to heat stress and/or flood regulation apart from possibly other thematic foci (regulating performance simulations).
4. the tool is readily available and open-source.

2.2|Analysis of the tools
The next step was to select criteria for comparing modeling tools. The selection is performed based on the knowledge and expertise of authors, informed by scientific literature focusing on modeling tools for spatial planning. The comparison is framed considering both the characteristics of the MT which serve to represent the urban system, and the informational possibilities the MT provides (Figure I).

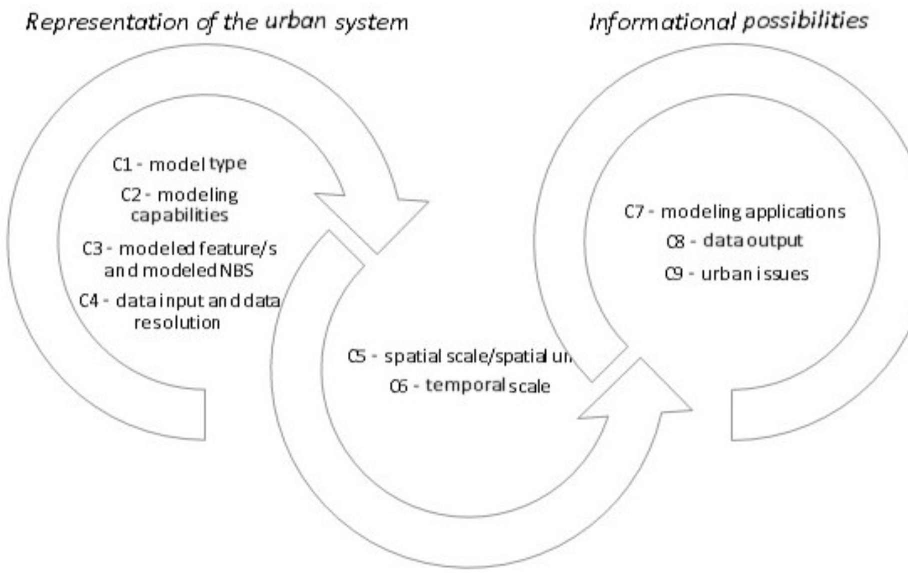

Figure 1 | NBS modeling tools' comparison criteria.
Source: authors.

For the representation of urban systems, including the NBS technologies, six criteria were considered.
The "model type" criterion (C1) refers to the main model approach, e.g. material/energy-oriented models or integrated models (Pelorosso, 2020). The "model capability" aspect (C2), refers more precisely to the various tool capacities such as accounting for hydrologic or hydraulic processes.
The "modeled features" criterion (C3) returns information on the main simulated system and subsystems while the "modeled NBS" specifies which NBS technology (green roofs, vertical greening, trees, permeable pavements, etc.) could expressly be designed in the tools.
The main input data required (C4) and the related resolution are additional criteria useful to better weigh up the complexity of the data entry tasks, which also depend on the spatial and temporal scales (C5 and C6) chosen for the scenario design and modeling. Indeed, the latter two can be considered the connecting criteria that determine how the informative outcomes result from the system representation, thus outlining the selected spatial resolution appropriate for the balance between the accuracy and efficiency of modeling.

For example, setting simulation options defines how the analysis is carried out and might imply choosing among computational methods and models such as flow routing and infiltration, flows routing models, or thermodynamic behavior of different land cover categories.
In flooding simulations, setting the temporal and spatial scale of the analysis might result in approaching the simulation as a one-dimensional model, or a two-dimensional surface flow model, as well as in running a long-term continuous simulation using a historical rainfall record or single event simulation.
In climate simulations, cooling capacity estimation might be approached by relying on empirical weights, derived from a limited number of case studies, or conducting experimental studies that provide insights into the relative effects of shade, albedo, and evapotranspiration.
The "modeling application" criterion (C7) is directly connected to the C1 and C2 and used to describe the typical utilization of the MT, for example, the design and sizing of drainage system components for flood control, the quantification of urban forest structure and environmental effects, the evaluation of the benefits of distributed GI implementation on water quantity and quality in urban streams.
"Output data" (C8) are proxies of the urban system performance. For instance, the flow peak releases from an urban catchment in a pre- and post-development scenario serve to calculate the peak flow ratio index, frequently chosen to evaluate how close the post-development scenario is to a required hydraulic invariance urban catchment asset (Pappalardo et al., 2017).
Similarly, computing the cooling capacity (CC) index provides insights into the relative effects of shade, and evapotranspiration (Geneletti et al., 2019).
Based on the above criterion, the more generic "urban issues" criterion (C9) readily returns the climate-related hazard or other particular challenges the urban system is simulated to face.
The qualitative understanding of the potential for applicability of each MT in spatial planning through its integration into planning and decision support tools was based on the outcomes of MTs comparison.

3 | Results and discussion

Despite some authors advancing more complex definitions of NBS[1], the latter are still present in the scientific and grey literature mainly as green infrastructure and a great part of studies and research returned information on the modeling practice of stormwater green infrastructure.
Accordingly, the majority of identified MTs is applied to predict the water quality and water quantity impacts of different green infrastructure approaches. Other models concerning climate regulations allow to simulate environmental factors such as heat island effect and outdoor comfort.
In general, it is definitely more frequent to review studies focused on models that can predict a single or a limited range of environmental outcomes within a limited range of scales, and not necessarily used to design scenarios for spatial planning.
Table 1 includes the list of retrieved MTs, adding the main relevant characteristics and literature references for relevant studies. The tools fulfilling conditions no.1 to no.4 (Section 2.1) are greyed out and further compared as an example of the application of the proposed comparison criteria for the MTs investigation (section 2.2).

Table I | NBS Modeling Tools (MTs).

Modeling Tool	**Description**	**Type**	**References**
ARIES	Automatically assemble the most appropriate ES models based on a library of modular components, driven by context-specific data and machine-processed ES knowledge	Modeling platform	Villa et al. (2014)
Center for Neighborhood Technology Green Values National Stormwater Management Calculator (CNT Green Values)	Allows the user to evaluate what combination of Green Infrastructure Best Management Practices (BMPs) meets the necessary volume capacity capture goal in a cost-effective way	Spreadsheet tool	Rahman et al. (2023)
ENVI-met	It is a three-dimensional microclimate simulation software that looks at the complex	Software suite	Liu et al. (2021)

[1] Nature based Solutions are designed nature—similar to urban green infrastructure—that are implemented to address the urban challenges of climate change, food security, and water shortage, and disaster risk and are based on both the ES and GI concepts but are novel in that they are conceptualized and implemented (Haase, 2020).

	urban environment as a single system and consider the multitude of processes that take place between elements (Determination of evapotranspiration and sensible heat fluxes to and from the plant, consideration of façade and roof greening in relation to all energy flows, Short- and long-wave radiation fluxes taking into account shading, multiple reflections from surfaces, buildings, and vegetation, etc.)		
GreenPlan-IT	It informs the planning of Green Infrastructure at the Watershed Scale, optimizing the placing of green infrastructure in the landscape and tracking the effectiveness of these installations.	Decision Support System	Zi et al. (2021)
InVEST	It includes various models for quantifying, mapping, and valuing the benefits provided by terrestrial, freshwater, and marine systems. It can estimate the amount of ecosystem services that are provided on the current landscape or under future scenarios.	Software suite	Lourdes et al. (2022)
i-Tree (core programs: i-Tree Eco; i-Tree Design; i-Tree Landscape; i-Tree Hydro i-Tree Canopy; i-Tree MyTree)	It is designed to aid in assessing and monitoring their local forest resource and understanding the services and values provided by trees and forests (i-Tree Hydro simulates the effects on hourly stream flow and water quality due to changes in tree cover and impervious cover within a watershed; i-Tree Eco provides the user with info on number of trees, air pollution removal and health effects, carbon storage and sequestration, stormwater runoff reduction, and effects on buildings' energy use),	Software suite	Raum et al. (2019)
EPA's National Stormwater Calculator (SWC)	Allows the user to estimate the annual amount of rainwater and frequency of runoff from a specific site using green infrastructure as low-impact development controls.	Software tool	Bernagros et al. (2021)
EPA Stormwater Management Model (SWMM)	Serves as a dynamic rainfall-runoff simulation model used for a single event or long-term (continuous) simulation of runoff quantity and quality from primarily urban areas. It explicitly models the hydrologic performance of specific green infrastructure control measures	Software tool	Gironás et al. (2010)
SUSTAIN	A watershed-scale decision support system that combines tools for site suitability analysis, stormwater quality and quantity analysis, cost-effective Low Impact Development (LID) selection optimization, and evaluation of various LID options	Decision Support System	Lee et al. (2012)
UMEP	Open-access set of tools and models for urban climatology and climate-sensitive planning applications, mainly related to outdoor thermal comfort, consumption of urban energy, and climate change mitigation. The most important feature of the model is its complete integration in GIS, allowing users to use in a spatially explicit way all parameters of the model and, more importantly, to edit and map inputs and results directly in GIS.	Software tool (GIS plug-in)	Lindberg et al. (2018)
URBANBEATS	Urban Biophysical Environments and Technologies Simulator for different city-scale, regional, and neighborhood solutions. It opts for the exploration of the interactions between	Planning-Support System	Bach et al. (2013)

	policy, urban form, technological solutions, and stakeholder preferences		
Virginia Runoff Reduction Method (VRRM)	Allows the user to evaluate the effectiveness of different BMPs and BMP combinations for water quality compliance and water quantity control requirements	Spreadsheet tool	Golden et al. (2016)

This tools collection cannot be considered an exhaustive review of existing NBS modeling opportunities with valuable tools potentially missed due to the adopted search, selection criteria, and researchers'/experts' knowledge and perspectives. The authors are not aware of a more comprehensive list of modeling tools available for NBS urban regulating performances, though.
Results of the criteria-based comparison are presented in Table 2 for three different models that cover both the focused urban issues: SWMM model for flood control, UMEP for urban outdoor thermal comfort, and INVEST for integrated evaluations.

Tabe II | Suggested criteria for comparing Modeling Tools.

Criterion	**SWMM**	**UMEP**	**INVEST** (1) Urban Flood Risk Mitigation (2) Urban Cooling
C1 - model type	rainfall-runoff simulation model	thermodynamic model	(1)rainfall-runoff simulation model (2)shading and evapotranspiration models
C2 - modeling capabilities	hydrologic and hydraulic	urban climate estimations (urban radiation, energy and water balances)	(1)hydrologic (2)cooling capacity
C3 - modeled feature/s and modeled NBS	sub-catchments nodes links (conduits; roads) NBS (green roof; rain garden	Land cover raster	(1) land use/land cover raster (2) land use/land cover raster
C4 - Data input and data resolution	Meteorological data, land surface characteristics (e.g., impervious area and soil characteristics), drainage network characteristics, NBS characteristics – high resolution	Land cover DSM Climatic data	(1)Meteorological data, land surface characteristics (land use/land cover, rainfall depth, soil characteristics), vector map of building footprints (2) Air temperature, urban heat island effect land surface characteristics (land use/land cover, evapotranspiration, shade and albedo), vector map of building
C5 - spatial scale/spatial units	small (building and/or neighborhood level)	Small and medium	(1)watershed or sewershed boundaries (2) small
C6 - temporal scale	single (rainfall) event or long-term simulations	-	(1)single (rainfall) event
C7 - modeling applications	controlling site runoff using stormwater green infrastructure practices	Heat Island Outdoor thermal comfort	(1)qualitatively represents the effect of natural infrastructure on stormwater flooding and the avoided damage for built infrastructure (2) estimates the cooling effect of vegetation based on commonly available data on climate, land use/land cover, and (optionally) air conditioning use
C8 - Data output	Runoff volume, runoff rate, mean pollutant concentration, total pollutant load	Mean Radiant Temperature Heat Island Index Urban Energy Balance	(1)Runoff volume retention, the flood volume per watershed, potential damage to built infrastructure per watershed (2) Urban Heat Mitigation Index, value

			of Heat Reduction Service
C9 - Urban issues	Stormwater quality and quantity regulation	Climate Regulation	(1)Urban Flood risk mitigation (2)Urban Heat mitigation

Filling in the table fields, criteria by criteria, resulted in the emergence of critical issues and potentials for each of the MTs, further clarified in terms of "applicability" and discussed to derive some general considerations.
Namely, four second-level sub-criteria were singled out, to qualitatively define the overall level of MTs "applicability in spatial planning":

- the level of accessibility (in terms of expertise, know-how, or competence required).

Practitioners rarely pick up models, mainly due to their complexity, low user-friendliness, and the extensive training and time needed to generate relevant outputs (Kuller et al., 2018). Moreover, simpler models require less data that might be retrieved from publicly available databases, while more complex models require more data to provide the necessary parameters and calibration. SWMM requires relatively extensive input data and technical expertise but could potentially provide more accurate results; similarly, UMEP requires defining more physical parameters in a time-consuming modeling process. InVEST boasts a pretty good balance between limitations and simplifications of the model, which uses a simplified approach for runoff production and attenuation estimation but concurrently introduces high uncertainties. Albeit obvious, much effort must be put into determining, for each model being considered, the amount of data and the spatial and temporal resolution it requires.

- the existing/past application/implementation (in terms of case studies and actual planning processes).

Implementing MTs in real case studies or their integration into SP_DSS has to be considered an added value for a smoother NBS uptake in the urban environment. Planning support systems relying on MTs functionality facilitate stakeholder interaction, enable data organization, integration, and visualization, and enable option evaluation to inform and empower planning processes. The results have also been gathered to obtain examples of the MTs' integration into SP_DSS, to seize early insights on barriers and opportunities for improved spatial planning/decision support systems. SWMM has already been integrated into more or less complex planning and decision support systems such as GreenPlan-IT and URBANBEATS, confirming that it is considered perhaps the most reliable modeling tool for stormwater urban flooding.
However, even when the SP-DSS are GIS-based, few present methods are acknowledged to allow for spatial explicitness (URBANBEATS; ARIES); mostly the integration of spatial/location issues/variables, such as the consideration of land suitability for NBS measures is based on biophysical characteristics of the system with other fundamental aspects such as the urban form and/or planning regulations underrepresented (SUSTAIN). Furthermore, a few examples map out the areas where NBS planning needs to be prioritized to address environmental disparities resulting from high flooding risk or thermal discomfort intersecting with vulnerable communities and the demands' geography.

- the potential for MTs combination to address multifunctionality and multiple urban issues (looking at data input/output, spatial reference units, etc.).

The flexibility of the MT is the extent to which the tool can be applied for different planning tasks or coupled with other MTs to cover the extent to which all the relevant dimensions are taken into account; the level of detail of the MTs should match the perspective of participants so that the usability of the MTs is favored according to the specific planning issue (Pelzer, 2017). Compared MTs tools (Table II) all provide quantitative data, which are fundamental to design indicators to measure features or processes of the human-environmental urban system under various scenarios, characterized by issues such as flooding risk or heat stress. However, this output information is likely to be returned without being spatially explicit or mapped based on varying spatial reference units (Figure 2a; Figure 2b). That is, a further data processing effort might be required to obtain a coherent representation of scenarios and comparable mapping.

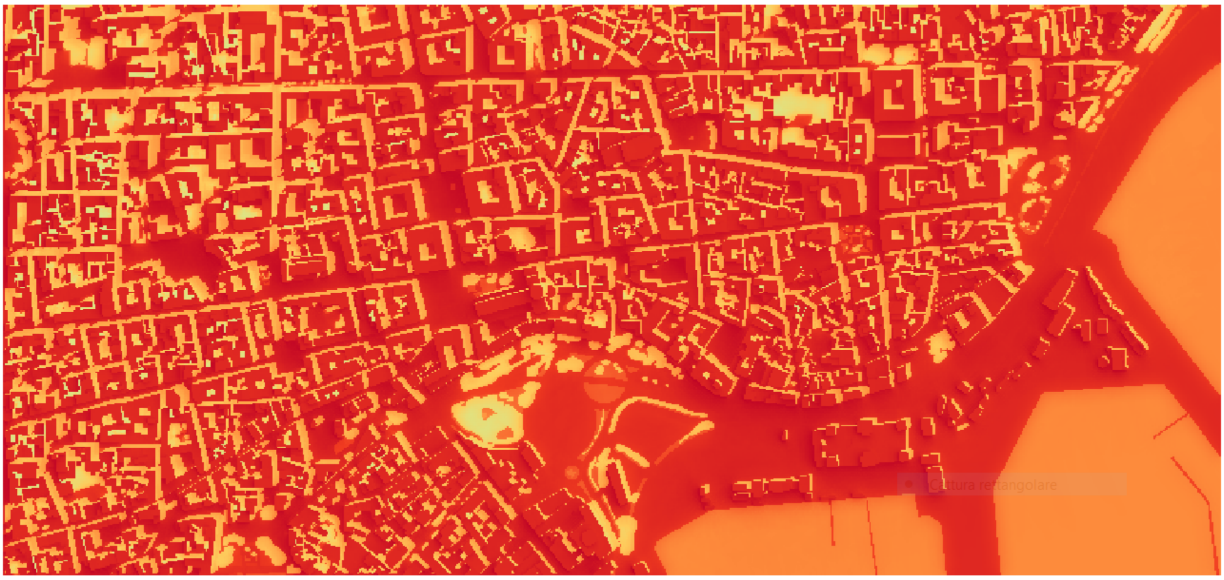

Figure 2a | Output of the UMEP model (Mean Radiant Temperature in Catania; Sicily).
Source: authors.

Figure 2b Output of the SWMM model (Water Depths in the surface drainage system of an urban sub-catchments in Avola, Sicily).
Source: authors.

In these regards, software suites such as InVEST, better respond to the needs of planners and decision-makers thanks to their modular and multi-service design and are the most popular tools among scholars. Both are frequently recommended to inform decisions about natural resource management by exploring how ecosystem changes are likely to lead to changes in benefits that flow to people.
Specific limitations in software capabilities could affect the usability of the tool, for instance when analyzing the future of a regeneration area it might be useful to compare the regulating performance of the combination of NBS but not all green measures can be explicitly modeled by all MTs and might be

approached differently (for example SWMM models green roofs, rain gardens, bio-retention cells, permeable pavements, vegetative swales but not trees which, perhaps counter-intuitively, "can be simulated as an impervious surface, with depression storage (interception), whose runoff is onto an adjacent or underlying pervious surface" (Rossman 2015); InVEST proxies the NBS by modifying land cover properties but the resolution should be small enough to capture the effect of green spaces in the landscape; UMEP does not allow to simulate the effects on customized land cover categories).
Weighing the cost and accuracy of a simple model against gradually more complex models can assist in determining the level of accuracy needed to fulfill the planning aim, which can then be used to deploy staff and budget resources more effectively. For instance, when planning the future regeneration of a brownfield area with a group of environmental analysts and landscape architects, it might be very important to get an extremely detailed insight into the environmental factors (e.g. noise, air quality, etc.), whereas when a long-term vision for a region is developed coarser information might be more suited, with a lower level of detail (Pelzer, 2017).
To advance the knowledge of the NBS modeling tools and their suitability for spatial planning processes and practices, the incremental gain in accuracy of a particular model is probably not worth the incremental increase in cost.
However, designing a more advanced comprehensive SDSS to capture and evaluate the spatial complexity and geographic diversity of the benefits produced by different NBS might require more effort in approaching scenario modeling.

- the visual output and interactive characteristics

The extent to which the tool can directly respond to the users' questions and the extent to which the visual output is useful for the end-users is important, particularly if the intended users are not directly involved in the collaborative development of a complete SP-DSS and are rather more likely to be asked o suggested to implement the models in their policy and planning practice.

4 | Conclusions

The lack of systematic study into the practical usage of modeling tools after their invention and the low acceptance of spatial/planning decision support systems in planning practice has prevented urban planners from fully realizing the potential of NBS for regenerating cities against the consequences of extreme rain events and temperatures and toward more sustainable transitions. This condition reiterates the need to find more effective ways to put this accumulation of knowledge at the service of planning rationality and its instruments. Indeed, quantifying the services or putting a price on the natural assets provides a critical basis for accounting "nature" as part of the municipal assets and thus supports assets' management and enhancement. A variety of models are available for assessing the performance of green infrastructure practices in the urban environment. However, before selection, specific needs and resources at disposal must be identified. Defining the objective of the planning effort (thus the environmental parameters to include in the model, the spatial and temporal scale of simulations), determining the data requirements (amount and spatial and temporal resolution), and choosing the simplest model that can meet the objective will support the integration of relevant technical and environmental factors related to urban design, at all relevant scales at which the problems are to be addressed, into the planning process. Importantly, such an approach becomes useful in thoroughly justifying planning and policy choices against public resistance and political opposition. This paper investigated existing tools for NBS regulating performance modeling and recommended the use of comparison criteria to facilitate the identification of potential criticalities in MTs integration for SP_DSS, and to qualitatively evaluate their level of applicability in spatial planning.

Riferimenti bibliografici

Abou Jaoude G., Mumm O., Carlow V. M. (2022), "An Overview of Scenario Approaches: A Guide for Urban Design and Planning", in *Journal of Planning Literature*, vol. 37, no.3, pp. 467-487.
Bach P. M., McCarthy D. T., Deletic A. (2013), "UrbanBEATS: A strategic planning tool for exploring water sensitive futures", in *8th International Water Sensitive Urban Design Conference* (WSUD 2013). Gold Coast, Australia.
Bernagros J., Pankani D., Struck S., Deerhake M. (2021), "Estimating Regionalized Planning Costs of Green Infrastructure and Low-Impact Development Stormwater Management Practices: Updates to the

US Environmental Protection Agency's National Stormwater Calculator", in *Journal of Sustainable Water in the Built Environment*, vol. 7, no. 2.

Cortinovis C., Olsson P., Boke-Olén N., Hedlund K. (2022), "Scaling up nature-based solutions for climate-change adaptation: Potential and benefits in three European cities", in *Urban Forestry & Urban Greening*, vol. 67, 127450.

Geneletti D., Cortinovis C., Zardo, L., Blal Adem E. (2019), "Developing Ecosystem Service Models for Urban Planning: A Focus on Micro-Climate Regulation".SpringerBriefs in Environmental Science, pp. 31–42.

Gironás J., Roesner L. A., Rossman L. A., Davis J. (2010), "A new applications manual for the Storm Water Management Model (SWMM)", in *Environmental Modelling & Software*,vol. 25, no.6, pp. 813–814.

Haase D. (2020), "Integrating Ecosystem Services, Green Infrastructure and Nature-Based Solutions—New Perspectives in Sustainable Urban Land Management", in Weith T., Barkmann T., Gaasch N., Rogga S., Strauß C., Zscheischler J. (a cura di), *Sustainable Land Management in a European Context. A Co-Design Approach*, SpringerLink

Kuller M., Bach P. M., Ramirez-Lovering D., Deletic A. (2017), "Framing water sensitive urban design as part of the urban form: A critical review of tools for best planning practice", in *Environmental Modelling & Software*, vol. 96, pp. 265–282.

Kuller M., Farrelly M., Deletic A., Bach P.M. (2018), "Building effective Planning Support Systems for green urban water infrastructure-Practitioners' perceptions", in *Environmental Science and Policy*, vol. 89, pp. 153-162.

Lee J.G., Selvakumar A., Alvi K., Riverson J., Zhen J.X., Shoemaker L., Lai F.H. (2012), "A watershed-scale design optimization model for stormwater best management practices", in *Environ. Model. Software*, vol. 37, pp. 6-18,

Lindberg F.; Grimmond C. S. B.; Gabey A.; Huang B.; Kent C. W.; Sun T.; Theeuwes N. E.; Järvi L.; Ward H. C.; Capel-Timms I.; Chang Y.; Jonsson P.; Krave N.; Liu D.; Meyer D.; Olofson K. F. G.; Tan J.; Wästberg D.; Xue L.; Zhang Z. (2018), "Urban Multi-Scale Environmental Predictor (UMEP): An Integrated Tool for City-Based Climate Services.", in *Environmental Modelling & Software*, vol. 99, pp. 70–87.

Liu Z., Cheng W., Jim C. Y., Tobi Eniolu Morakinyo, Shi Y., Ng E. (2021), "Heat mitigation benefits of urban green and blue infrastructures: A systematic review of modeling techniques, validation and scenario simulation in ENVI-met V4", in *Building and Environment*, vol. 200, 107939.

Lourdes K. T., Hamel P., Gibbins C. N., Sanusi R., Azhar B., Lechner A. M. (2022), "Planning for green infrastructure using multiple urban ecosystem service models and multicriteria analysis", in *Landscape and Urban Planning*, vol.226, 104500.

Pappalardo V., Campisano A., Martinico F., Modica C., Barbarossa L. (2017), "A hydraulic invariance-based methodology for the implementation of storm-water release restrictions in urban land use master plans", in *Hydrological Processes*, vol. 31, no. 23, pp. 4046-4055.

Pelorosso R. (2020), Raffaele Pelorosso. (2020), "Modeling and urban planning: A systematic review of performance-based approaches", in *Sustainable Cities and Society*, vol. 52, 101867.

Pelzer P. (2017), "Usefulness of planning support systems: A conceptual framework and an empirical illustration", in *Transportation Research Part A: Policy and Practice*, vol.104, pp. 84-95.

Pons V., Abdalla H., Tscheikner-Gratl F., Alfredsen K., Sivertsen, E., Bertrand-Krajewski J.L., Muthanna TM. (2023), "Practice makes the model: A critical review of stormwater green infrastructure modelling practice", in *Water Research*, vol. 236, 119958.

Raum S., Hand K. L., Hall C., Edwards D. M., O'Brien L., Doick K.J. (2019), "Achieving impact from ecosystem assessment and valuation of urban greenspace: The case of i-Tree Eco in Great Britain", in *Landscape and Urban Planning*, vol. 190, 103590.

Sarabi S., Han Q., Bauke de Vries, Georges L. Romme A. (2022), "The nature-based solutions planning support system: A playground for site and solution prioritization", in *Sustainable Cities and Society*, vol. 78, 103608.

Villa F., Bagstad K. J., Voigt B., Johnson G. W., Portela R., Miroslav Honzák, Batker D. (2014), "A Methodology for Adaptable and Robust Ecosystem Services Assessment",in *PloS One*, vol. 9, no. 3. Voskamp, I. M., De Luca C, Polo-Ballinas M.B., Hulsman, H., Brolsma, R. (2021), "Nature-Based Solutions Tools for Planning Urban Climate Adaptation: State of the Art", in *Sustainability*, vol.13, no.11, 6381.

World Bank (2022), “Piloting Nature-based Solutions for Urban Cooling Overview”, Washington, DC: World Bank.
Zi T., Whipple A., Kauhanen P., Spotswood E., Grenier L., Grossinger R., Askevold R. (2021), “Trees and Hydrology in Urban Landscapes”, in *SFEI Contribution*, no. 1034. San Francisco Estuary Institute: Richmond, CA.

Sitografia

Golden, J., Steers, J., Cunningham, F., Brooks, J., Leach, B., & Cooper, R. (2016), “Commonwealth of Virginia department of environmental quality water permitting division”. https://swbmpvwrrc.wp.prod.es.cloud.vt.edu/wp-content/uploads/2017/11/GM16-2001-Virginia Runoff-Reduction-Method_V3.pdf
Rahman M. R., Kim H., Kwon D., and Lee J. (2023), “A Simulation-based Modeling Approach to Adapt Social-Ecological Green Infrastructure System for Resilient Urban Flood Management”, in EGU General Assembly 2023, Vienna, Austria, 24–28 Apr 2023, EGU23-4830. https://doi.org/10.5194/egusphere-egu23-4830.

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