Definition of an Integrated Theoretical Framework to Assess the NBS Suitability in Flood Risk Areas

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Abstract. Urban flood events are strongly affecting cities by compromising their whole system. Additionally, these events are becoming even more frequent due to the climate change effect. In this context, the urban and territorial planning require changing to plan the adaptation scenarios by considering the Nature-Based Solutions (NBS).

Consequently, this study aims to define an integrated theoretical framework to support decision makers, planners, technicians, freelances and public bodies in the assessment and design in the assessment of the more suitable NBS adaptation scenario. The proposed method includes InVEST modelling to quantify in biophysical terms the runoff mitigation effect due to NBS implementation. By combining this method with a novel extension of a tool of analysis and assessment: the D-A'WOT Analysis. This extension proposes the dynamic approach to the A'WOT to identify the dependent and independent variables that characterise a complex spatial system, as well as to solve the decisional problem by de-composing it in its simpler parts through a hierarchical approach. In this way, it can facilitate the identification of indicators which may support the identification of the most suitable alternative. The integration of the InVEST modelling and the multicriteria approach can trigger fruitful insights in the context of urban planning and design of site-specific interventions in priority areas and scaling up investments. On the one hand to contrast at flood risk and on the other hand to generate multiple benefits for a safer, sustainable and resilient quality of life.

Keywords: Nature-Based Solutions (NBS) · InVEST modeling · Decision-making

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1 Introduction

Today is widely shared a global awareness that the environment health is one of the main priorities of governmental agendas (United Nations 2015). The impact of anthropogenic activities in two centuries have led to the creation of an intergenerational debt (Mondini 2019) which must be extinguished to avoid an irreversible future for next generations (IPCC 2019). The increasing global temperatures, the draining of water bodies, the melting of glaciers and the consequent arise of sea levels, are revolutionizing the Nature's clock and causing an increase of unpredictable events. To mitigate and compensate the Man's mistakes, Nature-Based Solutions are retained ever more fundamental and thus helping the Socio-Ecological Systems (SES) to evolve, adapt and respond to perturbations (Gunderson and Holling 2002) in a more sustainable way.

The EU commission defines Nature-Based Solutions (NBS) as "[…] inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience. Such solutions bring more, and more diverse, nature and natural features and processes […] through locally adapted, resource-efficient and systemic interventions."[1]. NBS includes a wide range of interventions, their scale can vary in function of the biodiversity protection and their resilience, and these can be co-designed by local communities (Reid et al. 2018; Sutton-Grier et al. 2018; Watson et al. 2018; Keeler et al. 2019; Seddon et al. 2020; Dell'Anna et al. 2022). For example, NBS differ from Low Impact Development (LID), Sustainable Urban Drainage Systems (SUDS), Water Sensitive Urban Design (WSUD), and Blue-Green Infrastructure (BGI) because they can provide many benefits and co-benefits at multiple scale, where natural risk like floods can be mitigated and/or compensated (Qin et al. 2013; Martin-Mikle et al. 2015; Ahmed et al. 2017; Qi et al. 2020; O'Donnell et al. 2020; Quagliolo et al. 2021a; Alves et al. 2022).

Policy decisions needs to be ever more supported by suitable tools of analysis and assessment and bridge the gap between theorization and practice of novel paradigms such as the one of climate resilience.

The World Bank has developed a catalogue collecting NBS solutions to satisfy the increasing need of Decision and Policy makers to deliver infrastructures and services, and other interventions to the built environment, as well as to identify related investments (World Bank 2021).

The Global Program on Nature-Based Solutions for Climate Resilience financed by the partnership GFDRR (Global Facility for Disaster Reduction and Recovery) sustains low- and middle-income countries in the risk and vulnerability reduction through resilience building projects to respond at climate-change and natural disasters[2]. Particularly, specific projects are devoted to flood risk reduction with benefits such as the redirection drainage and storage infiltration of flood storm water, or the loss reduction of urban infrastructure, among others.

[1] European Commission: https://ec.europa.eu/info/research-and-innovation/research-area/environment/nature-based-solutions_en (Accessed: April 2022).

[2] Global Facility for Disaster Reduction and Recovery (GFDRR) https://www.gfdrr.org/en (Accessed April 2022). Global Program on Nature-Based solutions for climate resilience https://naturebasedsolutions.org/projects (Accessed April 2022).

Amidst the tools available in the relevant literature, the InVEST modelling and MCDA models whether combined may trigger useful insights for NBS design and assessment, thus supporting the adaptation of urban and territorial systems to extreme events, such as the flood and heavy rains.

It is important to underline that the present paper (re)start from a previous article of some of the authors (Quagliolo et al. 2023 in press) which employ the combination of the InVEST modelling with the Multicriteria Decision Analysis (MCDA) in a pilot cases study. Thanks to the interesting results obtained by that first application, the present paper continues that research in order to define a theoretical evaluation framework able to support Decision and Policy Makers in the assessment and planning of complex spatial systems affected by flood risk areas which require priority interventions.

The paper includes the following sections: a Methodology section devoted to the development of a literature review on InVEST modelling and a novel MCDA technique called D-A'WOT Analysis; a Theoretical proposal section which takes into account the main features of both the methodologies in order to develop a novel model; and a conclusive section that recapitulates the utility of the novel framework and envisions the next steps of this research work.

2 Methodology

This section deals with the theorization of a novel multidisciplinary framework to tackle the complexity and uncertainty of urban and territorial problems. This paper focuses on the need of Decision Makers to find suitable interventions able to respond to the occurrence of urban flood events that could, on the one hand, damage cities and their socio-economic axis, and on the other hand perturbate the whole Socio-Ecological System (SES), leading this to its reorganization (Gunderson 2010). The proposed method, as already said, recalls the research work developed in the paper (Quagliolo et al. 2023) and defines more deeply its theoretical structure, thus proposing a novelty in the family of decision support systems.

Particularly, the InVEST modelling can help prioritisation of intervention areas for NBS implementation (Kadaverugu et al. 2020; Salata et al. 2021). Through the biophysical assessment, quantification of NBS effects to mitigate climate/natural hazards while increasing a range of related benefit (i.e. social and economic) could be performed by implementing different scenarios (Quagliolo et al. 2021b).

The MCDA can help Decision Makers in the solution of multidimensional problems by considering the actors and stakeholder preferences. They can represent the complementary piece, on the one hand of Cost-Benefits Analysis and/or Discount-Cash Flow (CBA and DCFA) because can deal with multiple elements, including the monetary ones. On the other hand, these are complementary of procedures of sustainability assessment, because can help in the identification and assessment of alternative solutions, and thus supporting the selection of the best scenario and in the impact of objectives and actions annexed (Bottero and Mondini 2009; Bottero et al. 2021).

2.1 InVEST Modeling

To help quantifying NBS biophysical effects and ecosystem services (ES) processes, various modelling tools have been developed to integrate many natural and human components (Francesconi et al. 2016). Among others, InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs), ARIES (Artificial Intelligence for Ecosystem Services), SWAT (Soil and Water Assessment Tool) and LUCI (Land Utilization and Capability Indicator) are all freely downloadable software and require medium technical skills but a good knowledge of Ecosystem Services and their processes. Particularly, the modular InVEST tool simplify the process of mapping. This tool for integrated spatial evaluation assessment of ES was developed by the Natural Capital Project[3] (NatCap), a partnership between the Stanford University, University of Minnesota, The Nature Conservancy and the World Wildlife Fund to integrate ES value into decision making (www.naturalcapitalproject.org). Through the terrestrial, freshwater, coastal and marine Ecosystem Services maps, InVEST is specifically designed for urban planning evaluation, ranging from general environmental assessment to local scale evaluations and all the decisions are aimed at restoring and protecting the Natural Capital. One of the main advantages to InVEST employment is related essentially to the consistent format of data input and output of the models which facilitate their integration with other spatially explicit models for ecosystems assessment. Specifically, the Urban Flood Risk Mitigation (UFRM) model is a recent product (2019) of InVEST which focuses on urban areas' ability to reduce the runoff process due to extreme rainfall and flash flooding events. The UFRM model considers the potentiality of permeable green areas to mainly reduce runoff while slowing surface flows and creating space for water (as in floodplains or basins). The model output represents the amount of retained runoff per pixels assuming mainly the flood-prone areas due to the interaction between the permeable-impermeable surface layers (related to the land use type) and the soil drainage (depending on the soil characteristics).

Since the InVEST software works with spatial models, the elaboration of model inputs and outputs is conducted through the employment of GIS tools. The UFRM model solves the empirical representation of the hydrological aspects for estimating runoff production and retention ability in the study area (Sharp et al. 2020). By applying GIS-based approaches to elaborate model's production, the localization of the implementation NBS areas (opportunity spaces) is identified (Albert et al. 2020). Overall, the resulting spatial index provides a picture of the vulnerability pattern by presenting the biophysical assessment (Davies and Lafortezza 2019).

2.2 Multicriteria Techniques: The D-A'WOT Analysis

The techniques of Multicriteria Decision Analysis (MCDA) are well known to be suitable for dealing complex problems and considering the interests and expectations of multiple actors and stakeholders in a shared vision of potential urban and territorial transformation. The MCDA techniques are ever more considered within integrated assessment frameworks thanks to their flexibility and ability to consider both qualitative and quantitative features of a decision problem. Considering the MCDA classifications according

[3] Available at https://naturalcapitalproject.stanford.edu/software/invest.

to the weighting assignment (i.e. choice, description, ranking and sorting), the paper focuses on the ranking-based techniques. In fact, they can provide to the final users a clear classification of the alternatives based on the users' preferences and/or expertise. The A'WOT model was developed in the early 2000s by combining the Analytic Hierarchy Process (AHP) and the SWOT analysis (Kurttila et al. 2000; Kangas et al. 2001).

According to previous studies of some of the authors, we retain that the SWOT Analysis should be integrated by a dynamic approach, which can better support the resolution of decision problems characterized by interdependent relationships. For example, cities and territories are interested by physical and immaterial influences (e.g. transport infrastructures, or migration routes) and there are certain variables which are more influent than other variables, positive or negative. These could influence the design and the prioritization of policy interventions. Therefore, it is required a method capable to interpret the values and pressures and understand the dynamics that occur within the system.

According to the results obtained in a previous research work, the authors states that it is ever more required a dynamic approach for dealing with the complexity of spatial systems, and to analyze their general and site-specific features.

The A'WOT is thus extended by a dynamic approach, by substituting the conventional SWOT Analysis with the Dynamic SWOT Analysis (Bezzi 2005; Bevilacqua et al. 2019). If the classical SWOT Analysis takes a photograph of the elements of a decisional problem according to the strengths (S), weaknesses (W), opportunities (O) and threats (T), the Dynamic SWOT Analysis makes a step forward and assess the relationships between the same elements (Bezzi 2005). Therefore, we present this novel method as Dynamic A'WOT (or D-A'WOT).

The proposed extension is here contextualized in the field of risk analysis and management to help Decision Makers, and other bodies in the assessment and design of Nature-Based Solutions (NBS).

This technique combines the dynamic SWOT Analysis with the Analytic Hierarchy Process (AHP), on the one hand to identify the main elements which characterize a complex spatial problem and their influence relationships, and on the other hand, to assess their relevance in solving a complex problem, such as the identification of the most suitable NBS scenario to contrast at flood risk in critical areas.

The methodological steps which characterize the D-A'WOT Analysis are provided below:

1. Data collection to identify the main elements of the decision problem under investigation. In the case of complex spatial systems, it is useful to develop territorial knowledge analysis through GIS methods and enriched with information material such as main national, regional and data sources, plans and regulations in force, or local knowledge, among others;
2. Importing the elements in the SWOT Analysis: in this step it is possible to analyze the values and the pressures as endogenous and exogeneous factors of the complex spatial system, by clustering them according to the Strengths (S), Weaknesses (W), Opportunities (O) and Threats (T). It is possible to use the conventional "four quadrants" configuration, recent extensions like the STEEP and SWOT Analysis (Szigeti et al. 2011), infographics, etc. The configuration choice may depend also on the

amount of data and features to be highlighted. A useful step is the codification of each element of the SWOT Analysis in order to create a bridge with the subsequent step and thus facilitating its development. The SWOT Analysis can be designed by team groups (i.e. desktop modality), or built by participants who are close to the decisional problem and able to provide useful information (i.e. participatory modality). However, independently from the modality choice, the SWOT Analysis can deliver a photograph of the decision problem and embryonal objectives and strategies which will be explicated through scenario building tools (Amer et al. 2013);

3. Development of the D-SWOT Analysis: each codified element is imported within a matrix (e.g. Excel environment) and evaluated according to a quali-quantitative scale, where 0 means lack of influence between two elements, scores as +1 means positive interaction between two elements and +2 labels a very positive synergy between them, whereas the scores −1 and −2 label a limitation of an element with respect to another and a potential nullification (Bezzi 2005). Once having filled the matrix, it is possible to summarize the scores in rows and in columns thus obtaining the dependent and independent variables which are useful to select the most relevant criteria that will be considered in the core of the assessment process;
4. Structuring of the decision problem. The criteria and related sub-criteria (or indicators) are organized according to a hierarchical approach which is typical of the Analytic Hierarchy Process (AHP) and connected to a defined set of alternatives with the purpose of finding the most suitable scenario (Saaty 2004).
5. Evaluation. This step follows the conventional multicriteria procedure: i) hierarchical configuration of the criteria and sub-criteria; ii) pairwise comparisons at the level of criteria and then of sub-criteria; iii) aggregation of the final priorities; iv) synthesis into the global priorities.
6. Ranking of the alternative scenarios and final check. In this final step, the alternatives are ranked from the most relevant to the least relevant. Then, their stability is checked through the sensitivity analysis and according to the "what if" approach (Razavi et al. 2021).

3 Theoretical Proposal

As shown in Fig. 1, the integrated approach here presented is constituted by three stages: the *ex-ante, in-itinere* and *ex-post* evaluation. In the *ex-ante* and *in-itinere* phases, the physical-environmental and performance analysis have been developed through the employment of InVEST modelling integrated with GIS tools. Specifically, this method can help in the identification of the priority intervention areas, intended as those interested by high flood risk. From the *ex-ante* to the *in-itinere* phase, the physical performance analysis can quantify the biophysical effect related to the NBS implementation to reduce the runoff production derived from rainfall events.

The MCDA, developing in this paper the D-A'WOT as the combination of the D-SWOT Analysis and the AHP method, can integrate the physical environmental and performance analyses in the *ex-ante* and *in-itinere* phases on different features. First, the criteria identification can also derive from data elaborated with GIS, InVEST, as well as from D-SWOT Analysis. Second, the D-A'WOT assessment can accompany

the three stages of the evaluation procedure and thus supporting the refinement of the NBS implementation. In this way, it is possible to deliver to Decision and Policy Makers an efficient-efficacy adaptation scenario. Moreover, the method can support the impact assessment of this scenario, positive and/or negative (e.g. increase of ecological connectivity, or financial availability) and providing in the *ex-post* phase, the scenario performance and helping the Decision and Policy Makers to identify potential mitigation and compensation actions.

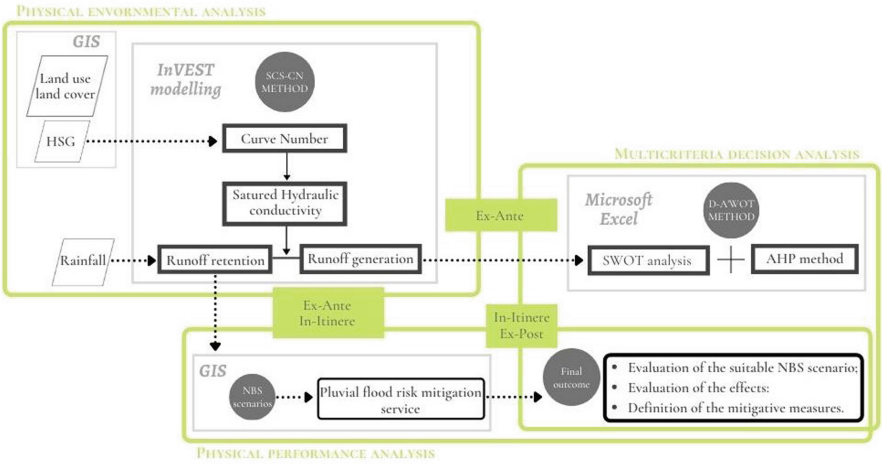

Fig. 1. Integrated theoretical framework

4 Future Perspectives of the Research

This paper has described a theoretical decision supporting framework that integrated the InVEST modelling with the MCDA in order to help Decision and Policy Makers in the assessment and design of NBS adaptation scenarios to contrast flood risk. It has underlined the value of NBS-based interventions within urban and territorial transformation and the potential benefits which may be generated for local community. It emerged also the need to implement them in policy decisions according to a systemic perspective (Lafortezza et al. 2018; Palomo et al. 2021).

Pros and cons of the individual methods are identified and reported as follows. Concerning the InVEST modelling, one limitation is that it synthesizes the hydrological urban aspects through a simple method (SCS-CN method). On the other hand, it allows to return numerical and quantifiable values in biophysical terms for the ecological measurement and for the flood reduction related to a given NBS intervention.

The D-A'WOT reunifies the analysis and the assessment phases in a unique method. This can help the users to manage and solve the decision problem since the early stages, until to its resolution. This can accompany both the planning and assessment along with the *ex-ante*, *in-itinere* and *ex-post* stages.

A limit of the D-A'WOT can be related to the difficulty of evaluating the influence relationships between numerous elements through the D-SWOT Analysis. Therefore, it is important to select a well and reasonable number of elements and supported by an expert knowledge.

The theoretical and methodological definition of this method, and the application developed in the previous work of the authors raised a number of reasonable perspectives to follow the next steps of this research.

As future perspective, the results of the D-A'WOT could be further extended with GIS methods, and thus making the methodological proposal of this paper even more integrated. Particularly, the dependent and independent variables obtained through the D-SWOT referred to a Socio-Ecological System (SES) and the set of weights obtained through the pairwise comparison method, will be combined and spatialized as suitability maps. In this way, the outputs of InVEST modelling and of the D-A'WOT can deliver as outcome the most suitable sites to localise the best NBS intervention, according to a SES perspective. The next steps of this research work will contribute to a practical advance of the Multicriteria Spatial Decision Support System (MCSDSS) (Malczewski 2006; Treves et al. 2020).

A future perspective for InVEST is to integrate the biophysical flood assessment with the economic estimation of flood damages to finally calculate the NBS cost-benefit analysis (Quagliolo et al. 2021a; 2021b).

The proposed extension has been theorized in the context of risk analysis and management, and it will apply to other issues which characterize the overall complexity of SES. Starting from the application in the paper (Quagliolo et al. 2023), this integrated framework will be applied to other similar territories interested by flooding criticalities. The local scale (i.e. Municipality or districts) will be considered in order to implement the concept of urban resilience related to flood risk.

It will be further explored the integration of specific dynamic models, such as System Dynamics Models and Lotka-Volterra cooperative models (Assumma et al. 2020) to predict potential evolution scenarios to tackle the climate change effect with socio-economic variables and the economic impact, positive or negative, which could be caused by a potential loss, as well as the possible benefits delivered by the NBS solution.

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