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Towards a software-supported operationalization of neighborhood sustainability assessment tools: Combining problem structuring methods and multicriteria decision analysis

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ABSTRACT

How can measuring urban sustainability foster creativity in designing assessment models? This paper addresses this question by presenting a multi-methodological approach for developing an operational, synthetic and site-based Neighborhood Sustainability Assessment Tool (NSAT) to support urban design. By integrating the Strategic Choice Approach and Analytic Hierarchy Process within the MuVAM (Multi-Values Appraisal Methodology) software, the framework enables a dynamic combination of qualitative and quantitative assessments, enhances stakeholder participation, and tailors sustainability evaluation to the specific contexts of urban projects. The approach is demonstrated through a case study on repurposing a large urban area into a hospital excellence hub, showcasing its applicability in complex urban transformations.

1. Introduction

Triggering real operationalization of urban policies requires reflection on the ways in which urban sustainability is measured, as well as a broader analytical/critical approach that questions its appropriateness, cogency and utilization (Logan et al., 2022).

Since the introduction of Sustainable Developments Goals (SDGs), a methodological shift towards "governance by numbers" occurred, bringing data into the policy discourse, with significant consequences for the types of knowledge required (Fukuda-Parr & McNeill, 2019). Until the SDGs, many global development agendas had been mainly qualitative statements concerning social and political priorities. With the adoption of the "language of numbers", policy evaluation was intended to be not only about what is included on policy agendas, but also about how to measure it and how quickly changes in the desired direction would be achieved.

The initial reflection on how to measure urban sustainability was further expanded to explore approaches and tools that would allow for creativity in the design of assessment models and paradigms for measuring urban sustainability performance (Kutty et al., 2023). Accordingly, the role of measurement in accompanying and structuring the design process, i.e. the maieutic role of evaluation, becomes evident.

Building on this reflection, exploring diverse approaches and tools for urban sustainability measurement requires examining specific methods that facilitate creativity in designing assessment models. To deepen this consideration, we consider the Neighborhood Sustainable Assessment Tools (NSATs - Sharifi et al., 2021). These are an evolution of the Sustainable Assessment Tools (SATs - Mahmoud et al., 2019), multicriteria tools voluntarily applied, developed to assess the performance of individual buildings with respect to energy/environmental performance. The NSATs expand the spatial scale and aim to measure the complex building-urban relationships being oriented to assess and measure sustainability considering the three pillars (environment, economy and society) in a cultural and institutional perspective (Bervar & Bertoncelj, 2016; Komeily & Srinivasan, 2015, 2016; Littig & Griessler, 2005; Reith & Orova, 2015).

Although NSATs are to date well positioned for measuring urban sustainability (Elkamhawy et al., 2024), they present three main problems:

i) They demonstrate an unbalance coverage of the sustainability aspects, putting emphasis on energy/environmental performance and embedding social, cultural and institutional problems into generic planning aspects (Adewumi et al., 2019; Larimian & Sadeghi, 2021);
ii) They are based on quantitative indicators and top-down approaches (Sharifi et al., 2021). The stakeholders' participation in NSATs is often limited, causing a lack of representativeness of local demand (Holden et al., 2016; Lin & Shih, 2018) and increasing the risk of conflictual situations;
iii) They propose generalized and inflexible criteria and indicators that fail to capture the specificities of the urban transformations to which they are applied in the perspective that sustainability is not a static goal (Ramiller, 2019). Accordingly, the mandatory numerous cri-

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teria and indicators of the NSATs could be irrelevant to the urban transformation in exam or inapplicable in relation to the design phase in which the NSAT application is needed.

While issue (i) is addressed in the paper by Penza and Abastante (2024) in which the development of a new NSAT is illustrated, this research focuses on issues (ii) and (iii) by proposing a participatory theoretical approach to structure the decision-making problem, highlighting the crucial and urgent aspects to be addressed by NSATs and contributing to the selection of the most relevant indicators with respect to a specific urban transformation and a specific moment in the urban design process.

This contribution deals with the limitations of conventional quantitative, top-down tools by introducing a method that is participatory and partly qualitative. Adopting such an approach allows all stakeholders to engage, breaking down the issues using accessible language and enabling broader discussions on any sustainability aspects deemed important in the specific context and phase of the process (preliminary/strategic, intermediate, definitive).

The paper seeks to answer the following research question: how to design an operational, synthetic and site-based NSAT able to support the urban design considering a specific phase of the decision-making process? To pursue this objective, the research proposes a multi-methodology combining the Strategic Choice Approach (SCA - Friend & Hickling, 2005) and the Analytical Hierarchy Process (AHP - Saaty 1980, 1990), through an innovative path, allowing the two methodologies to be combined in a single interactive flow that can be customized according to the users and the type of case analyzed. The proposed methodology can be applied through a new software called MuVAM (Multi-Values Appraisal Methodology), developed by the first author and the DEM Future software house (Demfuture 2024), engineered to support decision-making processes related to complex problems.

An NSAT, called ITACA-Urban Scale Plus (ITACA-USPlus - Penza & Abastante, 2024), is used to illustrate the effectiveness of the developed method.

This paper explores how one or more “operational versions” of ITACA-USPlus can be defined through a shared participatory process considering commitment, motivation and institutional/non-institutional support as an integrate part of the urban sustainability design. Since it is difficult to reach a single uncontested representation of the sustainability problem under consideration, we show how it can be used to inform negotiations on the nature of the urban transformation under consideration.

Section 2 briefly describes the NSATs with particular reference to ITACA-USPlus. Section 3 then illustrates the theoretical aspects of the methodology proposed and the main characteristics of MuVAM followed by a description of the case study provided in Section 4 and a discussion of the results obtained during a master’s course of lifelong learning (Section 5). The paper then concludes with comments about the benefits and difficulties of applying this method and possible future developments.

2. Sustainable assessment tools and neighborhood sustainable assessment tools

The SATs originated in the 1990s as protocols for energy and environmental impacts certification of buildings in response to a specific demand coming from the expanding real estate market: the request for energy efficiency guarantees of large commercial and residential complexes and the consequent assessment of their market value (Abastante et al., 2021; Cerin et al., 2014).

In the wake of the first SAT developed by the Leadership in Energy and Environmental Design (LEED) in the USA, several different protocols were born, and their use is well-established to date.

After the 2008 economic crisis, new challenges in architectural and urban design emerged, focusing on climate change, access to common resources, and social inequalities (Secchi, 2013). These challenges revealed that the prior focus on "green" buildings was insufficient, requiring new tools to capture complex interrelationships and unconventional cause-and-effect patterns (Attaniese and Acierno, 2017). With the rise of the three pillars of sustainability and the need for cultural and institutional guidance (Purvis et al., 2019; Komeily & Srinivasan, 2016; Reith & Orova, 2015), the focus of assessment tools has shifted from simply certifying "green" buildings to supporting sustainable urban transformation projects.

SATs have been then joined by the NSATs, assessment protocols that look not at the performance of individual buildings but at urban transformations at the district and city scale. By broadening the spatial scale of assessment, NSATs also flank the assessment of environmental sustainability with social, economic, institutional and cultural sustainability aspects that arise from relationships among portions of urban areas and therefore cannot be assessed through the observation of individual buildings (Zichi, 2020).

From a methodological point of view, the NSATs are multicriteria methods based on a rating system (Abastante, 2023; Sharifi & Murayama, 2013), characterized by a hierarchical structure consisting of:

- Areas: general macro-themes of sustainability (i.e. environment, governance, society);
- Categories: declinations of the Areas referring to specific sets of objectives. Each Area is divided into one or more Categories depending on the complexity of the Area itself and the NSAT considered;
- Performance Criteria: performance measures through which an urban project can be assessed, monitored and certified. Each category is broken down into one or more performance Criteria measured through indicators.

Each element of the hierarchical structure is assigned a weight, giving different importance to each Area, Category, and Criterion/Indicator within each NSAT. Urban projects are then evaluated based on their performance against each indicator, and a score is assigned: this system of weights and scores produces an overall sustainability index for the project. On this general hierarchical structure, each NSAT has specificities in terms of indicators and weights, reflecting the different needs and sensitivities of various national and international urban contexts (Sharifi, 2021).

This research focuses on the NSAT ITACA-USPlus (Penza & Abastante, 2024), developed by the second author starting from the ITACA-Urban Scale (ITACA-US) promoted by the Italian government (Attaianese & Acierno, 2017). Conceived in 2016 by the "Institute for Innovation and Transparency in Procurement and Environmental Compatibility" (Marzi, 2019) and modified in 2020, it aims to assess and monitor urban transformations. Despite its importance, ITACA-US has several issues: it prioritizes environmental sustainability, neglects social and institutional aspects, lacks clear metrics for some Criteria, and doesn’t group all Criteria into Categories or Areas, complicating the weighting process. ITACA-USPlus addresses these issues by incorporating all sustainability dimensions and organizing measurable Criteria within a clear hierarchical structure; it consists of 10 Areas subdivided into 25 Categories in turn declined into 54 measurable performance Criteria (Table 1).

ITACA-USPlus is a comprehensive tool in terms of sustainability content and rating methodology but is currently complex in its application since i) measuring 54 performance Criteria requires a huge cognitive and data effort as well as an amount of time that planners and Public Administrations (PAs) often do not have available; ii) the 54 performance Criteria pertain to different phases of the project-process. Some Criteria could be suitable for supporting the definition of the design idea from a strategy perspective, other Criteria could be relevant with respect to the implementation phase of urban transformation while other Criteria may be suitable for performance monitoring in ex-post phases; iii) the performance Criteria, Categories and Areas are of general nature and may not necessarily be suitable for measuring any urban transformation regardless of the context in which it is to be implemented.

Table 1
ITACA-USPlus structure.

AREA	CATEGORY	CRITERION
GOVERNANCE	ADMINISTRATION	1.01 - Participation (ex-ante)
		1.02 - Social management of the worksite
		1.03 - Participation (in itinere, ex-post)
	INNOVATION	1.04 - Green building policy and incentives
ARCHITECTURAL ASPECTS	APPROACH	3.01 - Project preparation methods
		3.02 - Design Team Qualification
	PROCESS	3.03 - Management Criteria
		3.04 - LCA
URBAN ASPECTS	SOIL USE	2.01 - Adjacency to the consolidated city
		2.02 - Soil Conservation
		2.03 - Conservation of the Built Environment
		2.04 - Redevelopment of brownfield sites
	URBAN LANDSCAPE QUALITY	2.05 - Relationship with the context
		2.06 - Social role of public space
		2.07 - Parking areas
MOBILITY/ACCESSIBILITY	PUBLIC TRANSPORT	8.01 - Road network scale
		8.02 - Public transport accessibility
		8.03 - Availability of safe bicycle routes
		8.04 - Pedestrian routes accessibility
		8.05 - Shared mobility accessibility
	ROAD SAFETY	8.06.1 - Road safety (ex-ante, ex-post monitoring)
		8.06.2 - Road safety (design)
PUBLIC SPACES	HEALTH	4.01 - Relevance of public open space
	PEDESTRIAN SAFETY	4.02 - Pedestrian routes safety
SOCIETY AND CULTURE	NEIGHBOURHOOD	9.01 - Proximity to services
		9.02 - Proximity to leisure facilities
	DIVERSIFICATION	9.03 - Mixing
		9.04 – Schools in the neighbourhood
URBAN METABOLISM	WATER	5.01 - Soil permeability
		5.02 - Intensity of water treatment
		5.03 - Wastewater management
	WASTE	5.04 - Waste collection accessibility
	LIGHT	5.05 - Light pollution
		5.06 - Solar orientation
	GAS/ARIA	5.07 – GHG emission
	SOUND	5.08 - Noise pollution
	MATERIALS	5.09 - Responsible infrastructure supply
	ENERGY	5.10 - Local Renewable Energy Production
		5.11 - Energy communities
		5.12 - Carbon dioxide emissions
		5.13 - CO^2 sequestration
BIODIVERSITY	ECOSYSTEM SERVICES	6.01 - Ecosystem services
		6.02 - Design of green areas (plant species)
ADAPTATION	MITIGATION OF THE EFFECTS OF DROUGHT AND WATER SCARCITY	7.01 - Extraordinary water pipeline maintenance
	MITIGATION OF HEAT WAVES IN URBAN AREAS	7.02 - Increasing tree planting on streets, squares and parking areas
		7.03 - Intensification of natural urban ventilation
		7.04 - Heat island
	ADAPTATION TO EXTREME RAINFALL EVENTS AND HYDROGEOLOGICAL RISK	7.05 - Reduction of building pressure
		7.06 - Reducing the amount of rainwater entering the sewer system
ECONOMY	ACCESS TO HOUSING	10.01 - Residential property affordability
		10.02 - Residential rental affordability
		10.03 - Composition and variety of housing supply
		10.04 - Value stability
	ACCESS TO EMPLOYMENT	10.05 - Employment potential

The research conveyed in this paper proposes a replicable approach to break down and reduce the ITACA-USPlus into a series of synthetic tools that are site-based (capable of supporting and measuring the performance of an urban project considering the context in which it is embedded) and process-based (relevant with respect to the design phase in which it is applied).

3. The methodology and the software

3.1. A multi-methodology combining SCA and AHP

Having identified the design of an NSATs as an example of a socio-technical phenomenon (Latour, 2005; Yaneva, 2009) with the peculiarities that contradistinguish the context of sustainable urban development, we considered that a specific multi-methodology was particularly suitable for addressing the topic.

This multi-methodology merges a Problem Structuring Method (PSM - Rosenhead, 1989, 1996; Rosenhead & Mingers, 2001) and a Multicriteria Decision Analysis (MCDA - Belton & Stewart, 2010), a combination that should allow to discuss "facts" and "values" in an integrated way (for additional insights, see Lami & Todella, 2023).

Problem Structuring Methods (PSMs) are participatory and interactive approaches focused on structuring problems rather than directly solving them (Rosenhead, 1996). They emerged to address the limitations of traditional Operational Research and decision analysis in dealing with complex, ill-structured problems. PSMs assume that real-world problem situations rarely have a single, uncontested interpretation. Instead, they emphasize representing problems through multiple perspectives. Early-stage visual models, as opposed to purely analytical ones, facilitate understanding, discussion, stakeholder engagement and the identification of potential improvements (Lami & Todella, 2019). PSMs can assist stakeholders or participants in the comprehension of several issues and their relations in a problematic situation (Coelho et al., 2010), and to properly participate in the process and prior to defining appropriate actions (Cambrainha & Fontana, 2018; Lami & White, 2022).

MCDA is a broad set of methodologies designed to systematically evaluate alternatives based on multiple, often conflicting and incommensurable dimensions. These approaches provide a structured framework for decision-making by assessing alternatives against well-defined criteria, ensuring a rational and quite transparent evaluation process. (Keeney & Raiffa, 1976; Figueira et al., 2016; Abastante, 2016).

Multiple criteria can be simultaneously considered in complex situations to assist decision-makers in integrating diverse options that align with stakeholder preferences within both, prospective and retrospective frameworks. Their active participation is a central aspect of the approach. Indeed, the MCDA should allow for a better exploration of the alternatives themselves, facilitate communication, and support shared solution finding, using the involved stakeholders' preferences (Dimitriou et al., 2016; Marleau Donais et al., 2019; Lami et al., 2021), dealing with prioritization and evaluation (Lami & Moroni, 2020).

The multi-methodology applied here, merging PSMs and MCDA (Marttunen et al. 2017), combines in particular SCA and AHP (Saaty, 2004).

Strategic Choice Approach (SCA) is one of the three most prominent (PSMs), alongside Soft Systems Methodology (SSM) and Strategic Options Development and Analysis (SODA), recognized for their applicability and volume of published research (Gomes & Scramm, 2022). SCA facilitates the identification of relationships between seemingly unrelated sectors and embraces the complexity and uncertainty inherent in decision-making. By exploring and comparing alternatives, participants clarify situations and navigate strategic choices. SCA generally begins with the identification of a series of related decision problems and consists of four phases (Friend & Hickling 2005):

1. *Shaping Mode*: In this initial phase, decision-makers identify and analyze key decision areas, evaluating their interconnections, importance, and urgency. These areas represent specific problems within a broader context. The goal is to define a subset of issues that will guide the decision-making process while establishing meaningful linkages to ensure a structured and integrated approach.
2. *Designing Mode*: Once decision areas are defined, a range of feasible options is identified within each area. These options are evaluated in pairs to determine potential incompatibilities, allowing for the formulation of comprehensive decision-making schemes. By systematically exploring all possible option combinations, decision-makers construct a decision tree that delineates the optimal sequencing of decisions and corresponding courses of action.
3. *Comparing Mode*: The decision schemes developed in the previous phase are then systematically compared based on multiple evaluation criteria defined by stakeholders. A structured comparison process, typically employing an advantage comparison grid, identifies the relative benefits and drawbacks of each scheme. This phase also highlights uncertainties arising from contextual factors, stakeholder values, and differing decision scopes, underscoring the need for strategies to manage uncertainty and foster stakeholder commitment over time.
4. *Choosing Mode*: In the final phase, decision-makers seek to reach agreements and formalize commitments to action. Uncertainties identified in the previous phase are addressed through exploratory actions designed to reduce ambiguity before making definitive choices. This process culminates in the development of a commitment package, which outlines immediate actions, targeted explorations to resolve uncertainties, and agreements on deferred decisions for future implementation.

The decision-making process in SCA includes, therefore, three main elements: perception of a problem; exploration of a possible solution; commitment to an action.

The Analytic Hierarchy Process AHP (Saaty, 1977, 1990) is an MCDA method based on ratio scale for measuring performances on considered criteria and the importance of these criteria (Ishizaka & Labib, 2011). The problem at hand is structured in AHP in a hierarchical way where the overall goal is set at the top of the hierarchy and the alternatives, being the object of the decision, are placed at the bottom of the hierarchy. The criteria on which the alternatives need to be evaluated are in the middle between the overall goal and the alternatives themselves. The fundamental idea is that it is more convenient to perform pairwise judgments rather than giving direct evaluations of performances. Using AHP, for each criterion, the DM is asked to compare each couple of alternatives indicating the preferred one and expressing the degree of preference with a verbal judgment on a nine point scale (Saaty, 1990). The numerical values identified are placed in square matrices of pairwise comparisons of the elements to determine the priorities between the elements belonging to each level of the hierarchy. For each level, it is necessary to construct as many pairwise comparison square matrices between the elements as there are elements ordered above. The data contained in the matrices of pairwise comparisons are used to derive the order of priority between the elements of each matrix. In mathematical terms, the priority scale is a vector of cardinal values expressing per row the priorities between the items being compared in pairwise comparisons. This vector coincides with the principal eigenvector of the pairwise comparison matrix. Once the local priorities have been determined, the global priorities can be calculated so that a ranking of the different alternatives can be constructed according to their relative scores. The composite weights are then determined by aggregating the weights of the entire hierarchy. This is done by following a path from the top of the hierarchy to each lowest level alternative and multiplying the weights along each segment of the path. The result of this aggregation is a normalized eigenvector of the total option weights (Saaty & Ozdemir, 2003; Saaty, 1980).

The proposed multimethodology adopts the first two phases of the SCA and uses the AHP pairwise comparison system for comparison, with subsequent calculation of the matrices and the eigenvector. There are several reasons for this choice:

1. Structuring the issue with SCA: When a decision-making issue emerges, problem structuring with SCA offers a comprehensive representation of the situation, facilitating effective analysis and enhancing awareness of the choices to be made.
2. Option designing with SCA: it creates alternative schemes, accounting for different perspectives in a transparent way; facilitates a better understanding about the available alternatives for each choice; then a decision can be conceived once the problem has been better defined.
3. Pairwise comparison through AHP: it supports the identification of well-defined, comprehensive, relevant, and operational criteria, enabling a transparent and systematic assessment of alternatives and allowing for a structured evaluation of multiple options across conflicting perspectives.
4. Defining a preferred solution through AHP: it mitigates information overload and complexity by integrating multidimensional data and consolidating preferences across criteria. Instead of generating a commitment package for further exploration, it identifies a preferred alternative.

Therefore, on the one hand, SCA enables the detection of relevant issues in the decision problems and their articulation in alternatives; on the other hand, the integration with AHP allows hierarchization of alternatives in an aggregated evaluation and discussion of the problem to

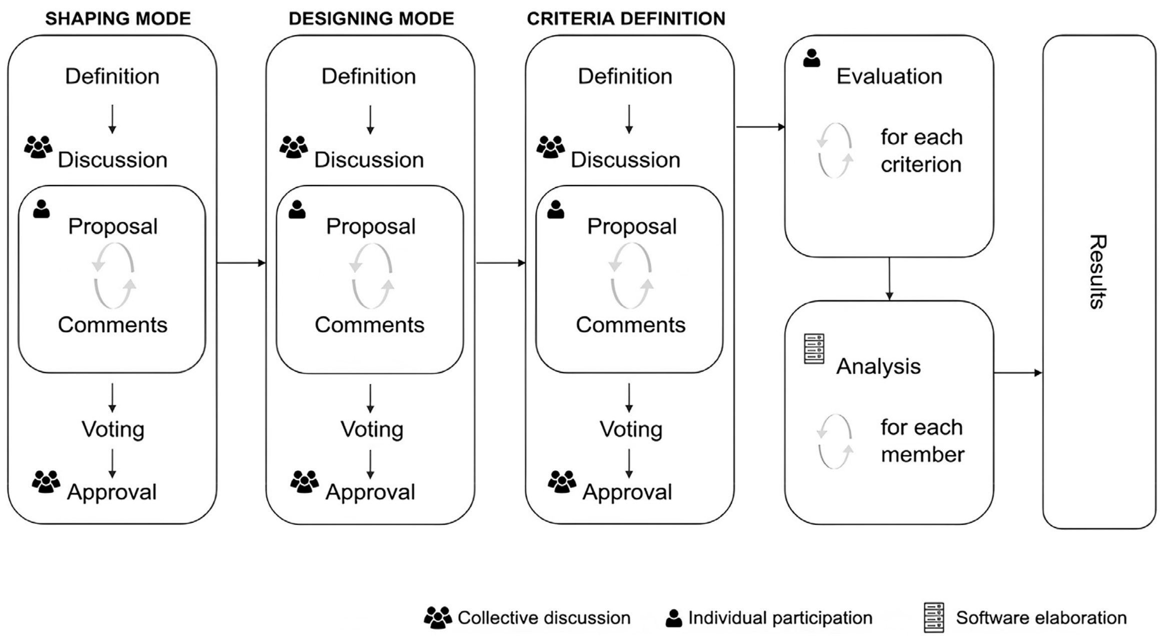

Fig. 1. Flow of interactions in MuVAM.

be faced in a more transparent and structured manner. SCA can make significant contributions to problem structuring addressing the decision problem through several steps and the associated forms of representation while the priorities among options are defined in general and qualitative terms.

Problem structuring is crucial to success in applying AHP, since the specific structure is the basis on which the criteria and objectives of the comparison are determined. In this sense, Option prioritization is the fundamental output that enables the method to determine which alternative is best.

3.1. The software: MuVAM

MuVAM is a web application divided into two programs: a *server*, running on one or more remote machines, and a *client*, running through a *web browser* on each user's machine. The *server* manages the synchronization of information relating to the problems to be analyzed, storing it and processing the solutions through a logical-mathematical algorithm. The *client* represents the graphical-logical interface through which users send and receive the aforementioned information, evaluate the various aspects of the problems being analyzed and verify the solutions obtained through a graphical restitution.

Each decision-making problem (also known as "project") is defined by a title, a target, a possible geographical location, documentary annexes and a set of users.

There are two approaches to problem analysis: the "in-place mode" allows on-site participants to collectively input and access real-time data from any machine, while the "remote mode" supports collaboration by synchronizing data entry and providing real-time feedback and comments.

The software application has four phases (Fig. 1). In the first phase, "Decision Areas" are defined to structure the decision problem. In "in-place mode," participants discuss and create the "Decision graph" and "Problem focus" through a shared interface. In "remote mode," each participant independently defines "Decision Areas," votes, and comments on others' proposals. This allows for asynchronous interaction. Afterward, participants individually connect the "Decision Areas" and save their "Decision graph." The software then merges the inputs to create a single "Problem focus" prioritizing the identified areas. In the second phase, participants define Options/Alternatives for each "Decision Area." In "in-place mode," they discuss as a group with one software user, identifying incompatibilities and generating an "Option Tree" of combined solutions. In "remote mode," participants propose Options/Alternatives individually, vote, and comment on others' proposals. The software then merges individual incompatibility grids into a single "Option Tree" of viable solutions. Throughout each phase, the *client* and *server* applications constantly communicate, providing instant feedback. For example, when a user proposes a hypothesis for a Decision Area, it is immediately shared with all connected devices, allowing others to evaluate, discuss, and approve it in real time.

Once possible solutions are identified, we enter the evaluation phase. Each participant, considering their own preferences, evaluates the solutions using shared, individually weighted criteria. First, participants define which solutions to analyze and the criteria for evaluation, similar to the AHP method. In the "in-place" mode, discussions happen in groups, with agreed solutions and criteria accepted through a single representative. In "remote" mode, solutions and criteria are evaluated individually and asynchronously. In both modes, the final analysis phase involves participants assigning weights to criteria and evaluating solutions via pairwise comparison, using software.

This phase is a key innovation of MuVAM, where users evaluate pairs of solutions on a 1 to 9 scale (Saaty, 1980) to determine how much one solution (A) is preferable to another (B). Unlike other methods, the system reduces evaluations by inferring preferences; for example, if A is better than B, and B is better than C, it skips the A vs. C comparison. The results are presented as a graduated preference scheme. Once evaluations are complete, the server processes the data using AHP methodology and stores the results.

The individual analyses are combined to produce a ranking of feasible solutions based on their total scores. This ranking, along with additional details like each user's partial scores, the criteria scores, and their weightings, is displayed in the client's interactive interface through diagrams, graphs, and tables, enabling a detailed analysis of participants' influence, choices, and key issues in the decision-making process.

4. The case study: the health park of research and innovation of Turin

The potential use and value of MuVAM to design a site-based operative NSAT are illustrated through a case study of the repurposing of large urban area into a pole of hospital excellence. This case study was chosen as an illustration of the method's general applicability for several reasons: i) it refers to the transformation of a large neighborhood characterized by the presence of multiple functions requiring for a formalized and structured sustainability design process; ii) it is a controversial urban transformation that fits into the dynamics of a city characterized by a high level of complexity and uncertainty; iii) it refers to a long-term decision-making process for which a solution has not yet been found; iv) the presence of multiple stakeholders' requires special attention from the perspective of the participatory process.

4.1. The context

The case study involves the Health Park of Research and Innovation (HPRI) in Turin, Italy, transforming the former Lingotto industrial area (314,000 sqm) after its abandonment in the early 2000s. Initiated in 2003, the reconversion was driven by the 2006 Winter Olympics. A memorandum of understanding was signed among key local entities to develop HPRI into a hospital excellence hub. Post-Olympics, the project faced setbacks due to fragmented ownership and lack of a cohesive strategic vision, causing the grandiose HPRI project to falter.

In 2013, negotiations resumed for the HPRI project, focusing on organizing spaces, properties, permitted uses, and urbanization. The 2018 feasibility study outlined guidelines for transforming the Lingotto area into an experimental university hospital, a teaching and research hub for medical and biomedical engineering, and residences for students, professors, researchers, and patients' relatives.

The HPRI project has stalled despite the launch of a 2018 tender for a public-private partnership due to several factors: the COVID-19 pandemic that necessitated a revision of space requirements, rising commodity prices that made the feasibility study obsolete, and a failed tender process. In November 2022, the National Anti-Corruption Authority appointed a commissioner to restart the negotiations.

This research is therefore consistent with the local debate, with the intention of understanding which synthetic NSAT is the most appropriate to support the definition of the HPRI project considering the new conditions.

4.2. MuVAM for ITACA-USPlus

4.2.1. Research setting

The definition of a synthetic, operational and site-based NSAT through MuVAM was the outcome of a three-day course at the second level Master's program "Methods and techniques for governing resilient territories. Towards integrated risk management in planning" (Politecnico di Torino). The participants were thirteen professionals attending a life-long learning course, experts in several sectors as energy, education, architecture, urban design and mobility, with different backgrounds and job positions as civil servants, members of research centres, free lancers. The geographical origin was also varied, distributed all over Italy and with one person participating from Colombia.

The course was held in remote via Zoom platform, where participants worked in four groups. During the first stage of the study the authors, starting from ITACA-USPlus, structured the decision problem ("How to define synthetic, operational and site-based NSAT for HPRI area?") according to the methodology applied by MuVAM. The following assumptions were made:

i) the NSAT's Categories are interpreted as Decision Areas;
ii) the Areas of the NSAT are interpreted as Comparison Areas;
iii) the Indicators of the NSAT are interpreted as Options.

At the beginning of the workshop, participants were given the problem structure along with illustrative case study documents. The second phase involved the workshop with MuVAM, alternating self-facilitated group work, collective discussions with the lecturers, and individual work sessions, as detailed in the following paragraphs. The last phase took place after the workshop, when six experts were interviewed with respect to the outcomes generated during the Master Course.

To evaluate the suitability of the proposed method for developing an operational NSAT, various data were collected and analyzed qualitatively, gathered from three main types of sources: observations, students' surveys, outcomes. At the end of the teaching module, the participants have been asked to fill in a Google questionnaire, structured with three open questions about the group interaction, the shared knowledge created and the final outcome.

4.2.2. Shaping mode

In the shaping mode, the participants have been asked to identify the most important Categories of the ITACA-USPlus interpreted in MuVAM as Decision Areas (Fig. 2).

Among the 25 Categories of ITACA-USPlus, 8 were considered fundamental and therefore designated as Decision Areas. In defining the Decision Focus, 4 Decision Areas were identified as secondary (namely Heat waves, Urban Landscape, Public Transport and Health Security) because of the time focus of the application. These elements require detailed design actions and were therefore not considered suitable for initiating the design at the preliminary strategic stage of the HPRI case study. 3 Decision Areas (i.e. Process, Energy, and Water) were identified as important. Given HPRI's troubled history, the "Process" Decision Area highlights the need to plan the entire design process and material life cycle meticulously. The "Energy" Decision Area is crucial due to the energy-intensive nature of HPRI, necessitating strategic solutions to manage consumption from the project's outset. Energy consumption has contributed to the latest design process stalemate, demanding immediate attention. Similarly, the "Water" Decision Area is vital, as healthcare settings have significant water needs, requiring detailed plans for wastewater and rainwater collection, storage, and recycling.

The Decision Area indicated as urgent is "Administration and Innovation" in the logic that all forms of participation in design decision-making should be considered and encouraged. To avoid further stops, the HPRI must be built in a participatory design perspective, involving institutional and non-institutional stakeholders through structured interlocutions and efficient communication.

From a methodological point of view, this turned out to be the longest phase: interaction with the software, supplemented by the use of other media (such as Zoom chats), made the discussion lively, similar to the dynamics observed "in presence" workshops, although it took place entirely in digital mode.

4.2.3. Designing mode

After having identified the Decision Areas and Focus, the participants have been asked to reflect about the Options, which are, in this application, the 54 Indicators of the ITACA-USPlus.

For each Decision Areas, participants identified 2 Options for a total of 8 Key Performance Indicators (KPI) capable of operationalizing the strategic directions defined in the Decision Areas (Table 2). Those have been collectively discussed to define incompatibilities through the incompatibility grid (Fig. 3).

The discussion among the participants brought to 6 incompatibilities, 4 of which pertain to the Options of the "Administration and Innovation" Decision Areas with reference to the "ex-post participation" KPI. For instance, it has been affirmed that this is not compatible with the "Life Cycle Assessment" in terms of timing, believing that the Options refer to different stages of the design and decision-making process.

Once the incompatibility grid has been defined, the "Option Tree" containing the viable solutions has been generated by MuVAM (Fig. 4, feasible solutions are highlighted in green).

From the application, 2 alternative NSATs emerge. Although these are not alternatives in the traditional sense, they become so with respect to the purpose and time of the application. Since the objective

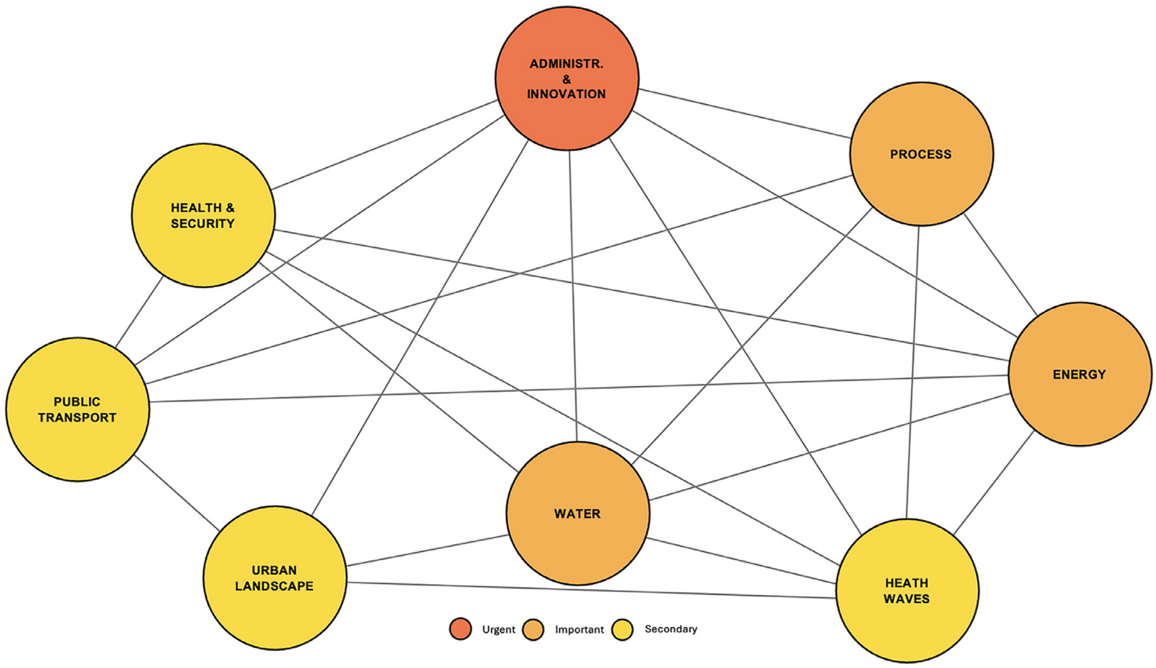

Fig. 2. Decision areas and focus.

Table 2
Decision options.

DECISION AREA	OPTION	DESCRIPTION
ADMINISTRATION/ INNOVATION	1.01 - Participation (ex-ante)	Stakeholders' involvement to attract funding
	1.03 - Participation (in itinere, ex-post)	Mitigation of the risk of fragmentation of the process
PROCESS	3.03 - Management Criteria	Planning public area development. Estimating operating costs
	3.04 - LCA	Environmental impact reduction
ENERGY	5.07 – GHG emission	Pollution reduction
	5.11 - Energy communities	Promoting the area's energy independence
WATER	5.03 - Wastewater management	Wastewater storage and reuse
	5.01 - Soil permeability	Use of permeable materials

of the research is to define an operational site-based and process-based NSAT, it is necessary to understand which ITACA-USPlus KPIs could be most useful to support the urban design project considering the preliminary/strategic design phase. In addition, in real context, policy makers and planners have little time to make decisions in urban transformations, therefore it is important to find ways to quickly develop an effective NSAT.

In the case study under examination (Fig. 4), the 2 NSATs are very similar both including the Options "management criteria", "energy communities" and "intensity of the water treatment". However, while Alternative A includes the Option "ex-ante participation", Alternative B emphasizes the importance of the "ex-post participation".

This result is in line with the history of the HPRI process in which the lack of decisions and the slowdown of project implementation are mainly due to a poor involvement of stakeholders from the earliest decision-making stages.

4.2.4. *Evaluation phase*

Participants were here asked to: i) collectively identify criteria through which comparing the 2 NSATs and to individually assign a weight to each of them (Table 3).

Table 3 shows the weights assigned by one participant as an example in which the "governance" is considered as the most important criterion (understood as the ability to support political, economic and management choices) followed by "climate change adaptation", "economic aspects", "public space design" and "mobility/accessibility".

The comparison step proceeded individually. Each participant evaluated the NSATs obtained by means of the AHP pairwise comparison (Fig. 5).

4.2.5. *Analysis*

Once the comparison phase has been completed by all participants, it has been possible to analyse the results in detail. In fact, MuVAM

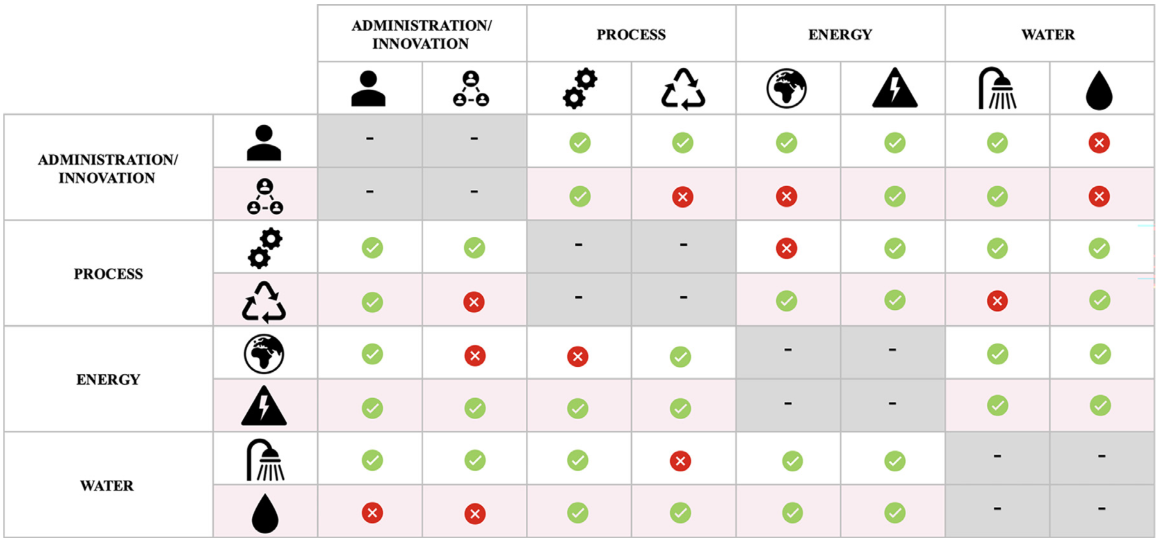

Fig. 3. Incompatibility.

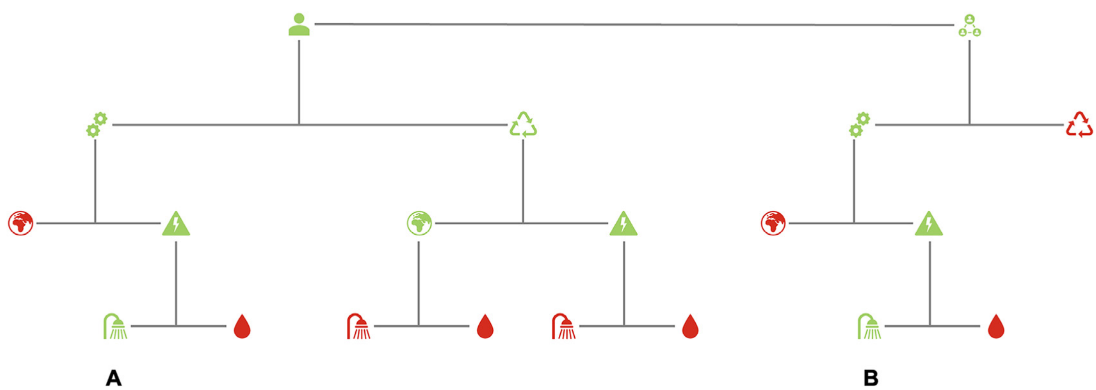

Fig. 4. Option tree.

Table 3
Comparison areas.

Comparison area	Weight	Description
GOVERNANCE	26 %	Careful assessment of management choices
PUBLIC SPACE DESIGN	16 %	Public space design containing health risks, implementing relationships and quality of life
CLIMATE CHANGE ADAPTATION	23 %	Orienting choices towards resilience
MOBILITY/ ACCESSIBILITY	14 %	Public transport and soft mobility integration
ECONOMIC ASPECTS	21 %	Reduction of management costs

first returns an overall result of the process in terms of preferred alternative (Fig. 6a) and score of each alternative against each criterion (Fig. 6b).

The NSAT “A” turned out to be the most performing alternative both considering the performance of each criterion and the overall approval rate (73 %).

This result is in line with the HPRI case study, and the objective of the analysis conducted. The NSAT “A” stresses the importance of the “ex-ante participation”, fundamental to properly support the definition of a HPRI project.

It is important to emphasize that MuVAM not only displays the alternative preferred by the group, but also preferences expressed by each individual participant allowing to trigger a debate and generate greater awareness of the values that guided the choices of individuals.

5. Discussion

The results obtained were discussed with 6 experts (3 in architectural and urban design, 1 in architectural design, SCA, and MuVAM, 1 in MCDA methodologies, and 1 in sustainability and energy assessment). After explaining the research objectives, experts were guided through the MuVAM process, illustrating the shaping mode for identifying Decision Areas. Experts deemed the selected Decision Areas relevant, especially "Administration and Innovation," considering the fragmented land ownership and environmental conditions. The HPRI interfaces with an urban tissue characterized by significant social wounds and a lack of identity. From this perspective, a structured decision-making process management is fundamental to the success of the project itself.

The Decision Area "Process" was also considered interesting and relevant with respect to the case study under examination and in relation to the definition of a NSATs to support the definition of a preliminary/strategic project. This Decision Area prompts a reflection with respect to the uses over time of the HPRI in which one of the fundamental themes is the management of the coexistence of several functions. This recalls the importance of the adaptability of spaces to accommodate new functions and future transformations that could be very rapid in relation to changing macro-economic conditions.

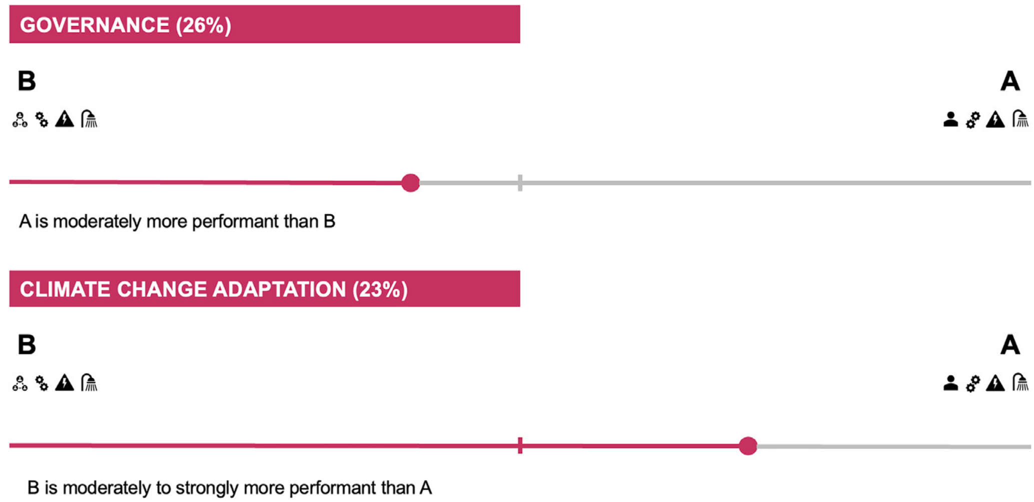

Fig. 5. Comparison.

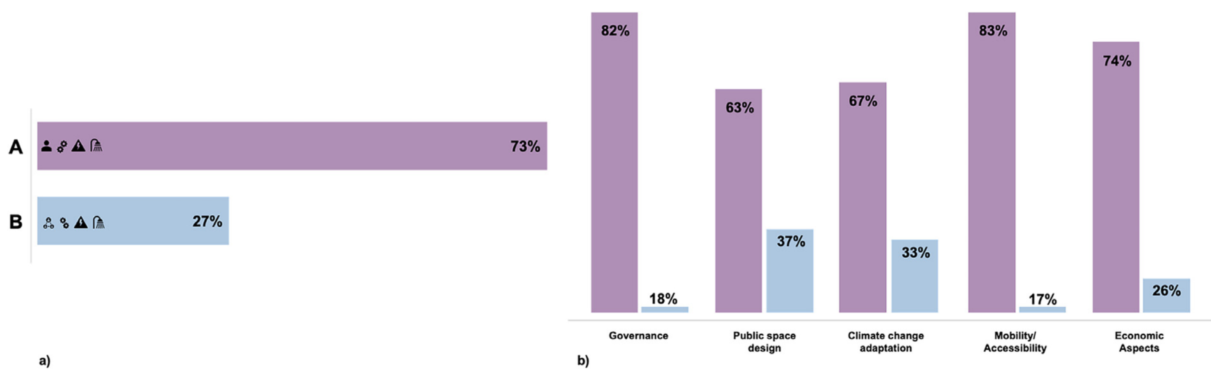

Fig. 6. Overall results.

The experts pointed out that the Categories "Heat Waves" and "Urban Landscape" are important issues for the design of sustainable cities, but in the developed NSAT they were indicated as secondary issues in terms of time. Following the site-based and process-based perspective of the developed NSAT, these Decision Areas could be taken up at a later stage of the design process and thus form the decision-making focus of a second NSAT. This was found to be particularly true for the "Urban Landscape" Decision Area, which is crucial for reflecting on performance morphology and understanding which forms of HPRI design would allow optimal performance to be achieved from numerous perspectives (Pont & Haupt, 2023).

Experts then discussed the logic behind defining Options and incompatibilities, which led to the Option Tree. They highlighted the critical issue of data availability and the complexity of measuring "ex-ante" and "ex-post" participation (Falanga, 2019). In order not to risk a fragmentation of the decision-making process, it is necessary not only to understand how to support the dynamics of participation, but also to study a planning of the participatory process as a whole, from the ex-ante to the ex-post phases. Finally, the experts emphasized that the Options identified for the "energy" Decision Area should include design solutions, such as the construction of photovoltaic parks, which require many hectares of available land that should be sized at an early stage in the design process.

With regard to the final results, experts found NSAT "A" reasonable for HPRI's transformation, highlighting "mobility/accessibility" and "public space design" as KPIs though the social dimension was underrepresented. They recommended including "society and culture" and emphasizing "adaptation to climate change" for its importance in international debates and potential to showcase good urban practices.

6. Conclusions

Drawing on the call to operationalize the NSATs (Dawodu et al., 2021; Pulgar Rubilar et al., 2023), this article set out to introduce a methodological approach and a new software designed to support public policymakers and professionals in monitoring the attainability and achievement of sustainability goals in urban transformations.

The chosen multi-methodology and software, combining qualitative and quanti-qualitative approaches, addresses three challenges: i) incorporating non-energy-related sustainability aspects, like social/institutional factors, that are not easily standardizable; ii) increasing participatory moments, including input from non-experts; iii) providing an easy-to-use, quick support tool.

Regarding these aspects, the case study showed how the iterative use of MuVAM software (combining SCA and AHP), triggers several patterns of participation at different stages:

- Shaping mode, Decision Areas: this step allows to carry out a systematic analysis of all the aspects of the problem considered important, bringing to light even those features related to urban complexity that are not immediately apparent (confirming that urban sustainability is not only an energy issue);
- Shaping mode, Focus: by forcing participants to define the connections between the different aspects of the decision-making problem to find the focus of the decision problem, this step enables synergies to emerge, which are fundamental because neighborhoods are not just the sum of individual urban characters, but they are above all the result of (sometimes unexpected and sometimes unwanted) synergies;

- Designing, Option Tree: the task of analyzing the incompatibility of Options can be rather quick due to the fact that the table is filled in automatically with respect to the diagonal, reducing cognitive load by highlighting issues in a composed and systemic way that anticipates problems;
- Evaluation phase: the identification of criteria, i.e. in this specific context requested to compare indicators, clarifies the nature of the data needed to proceed in a direction of effective implementation of the NSAT;
- Analysis: making explicit what would have been the results for the individuals and what is the result of the group's interaction, allows a traceability of the trade-offs to arrive at an NSAT that represents the most shared concept of sustainability possible.

These findings, derived from the answers of the Google questionnaire, the direct observation of the workshop by the authors and the interview with the experts described above, indicate that this can be an effective way to design synthetic and customized tools to assess the overall sustainability of specific urban transformations.

While this study is limited on a single case study, similar dynamics can be expected in relation to other NSATs that have different characteristics and various types of participants.

Future research will move along two tracks. On the one hand, it will study how to design operational NSATs combining SCA with different MCDA methodologies. The most effective choice could be to examine methodologies that use fuzzy approaches such as Fuzzy AHP (Liu et al., 2020) or the Best-Worst method (Rezaei, 2015) in order to better consider phenomena of uncertainty and ambiguity. On the other hand, completely different combinations of methodologies will be explored. Scholars could also further explore how the newest (and still understudied) aspects of sustainability, such as coexistence with the different forms of AI that permeate cities in more or less visible forms, together with concerns that have long been the object of evaluation of our choices, such as responsibility towards future generations, are interpreted in the development of NSATs.

In conclusion, the proposed approach and the MuVAM software offer a robust framework for integrating qualitative/quantitative assessments, enhancing stakeholder participation, and tailoring sustainability evaluation to the unique contexts of urban projects. These innovations have the potential to significantly improve the planning, implementation, and monitoring of sustainable urban transformations, making sustainability goals more accessible and measurable.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Isabella M. Lami: Writing – review & editing, Software, Conceptualization, Methodology, Writing – original draft, Data curation. **Francesca Abastante:** Validation, Writing – original draft, Conceptualization, Methodology, Writing – review & editing, Visualization, Investigation.

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