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The Contribution of NBS to Urban Resilience in Stormwater Management and Control: A Framework with Stakeholder Validation

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Abstract: Urban waters represent a crucial component for the enhancement of urban resilience due to their importance in cities. Nature-based solutions (NBS) have emerged as sustainable solutions to contribute to urban resilience in order to meet the challenges of climate change. In order to promote the use of NBS for increasing urban resilience, tools that demonstrate the value of this type of solutions over the long-term are required. A performance assessment system provides an adequate basis for demonstrating this value, as well as for diagnosing the current city situation, selecting and monitoring the implementation of solutions. Regarding NBS management, some assessment approaches have been published, focusing on assessing the effectiveness of NBS in the face of climate change and supporting their design and impact assessment. Nevertheless, an integrated approach to assess the NBS contribution for urban resilience has not been published. This paper presents a comprehensive resilience assessment framework (RAF) to evaluate the NBS contribution for urban resilience, focused on solutions for stormwater management and control. Furthermore, details on stakeholders' validation, with focus on the metrics' relevance and applicability to cities, is also presented.

Keywords: Ecosystem Services (ES); Nature-Based Solutions (NBS); Resilience Assessment Framework (RAF); stakeholders' validation; stormwater management and control; urban resilience

1. Introduction

Climate change has fostered the need to develop and improve urban resilience by promoting a resilient city's capabilities to absorb disruption, learn from the past, adapt, transform and prepare for the future. Resilience emerged as an interesting concept on cities, often theorized as highly complex adaptive systems [1,2]. Resilience is commonly understood as the capacity of a system to absorb disturbance and re-organize while undergoing change so as to still retain essentially the same function, structure, identity and feedbacks [3]. The concept of resilience emerged in the 1960s from the growing interest in ecology to determine population stability between communities. Resilience emerged as an interesting perspective on cities, often theorized as highly complex adaptive systems [4–6].

In the urban water cycle, the evolution of the drainage systems followed the evolution of the resilience concept, from one single point of view (e.g., economic or social resilience) to a broader and more inclusive definition, encompassing the multiple dimensions of urban resilience. Urban water services are of fundamental importance in the promotion of urban resilience. Urban waters are essential to support nature-based solutions (NBS) functions and to ensure the provision of ecosystem services from NBS, such as air quality improvement or urban heat island mitigation. Evaluating and enhancing resilience in the urban water cycle is a crucial step toward more sustainable urban water management [7].

Historically, the main objectives of urban drainage systems were to ensure efficient management of peak flows and adequate treatment of polluted waters, aiming to ensure public health and prevent flooding. More recently, integrated approaches for urban water management emerged and other key issues were identified for sustainable water management, such as surface and ground water quality, ecological concerns, and recreational uses [8].

The European Commission defines NBS as actions that aim to helps societies address a variety of environmental, social and economic challenges in a sustainable way [9]. In essence, NBS can be defined as living solutions inspired by, continuously supported by and using nature, which are designed to address several societal challenges in a resource-efficient perspective and to provide simultaneously economic and environmental benefits [9]. NBS involve actions for conservation or rehabilitation of natural ecosystems and improvement or creation of natural processes in modified or artificial ecosystems [10]. Some examples of NBS for stormwater management are infiltration basins, green roofs, constructed wetlands or swales with vegetation cover, among others.

In the water sector, the NBS concept can be found in technologies such as sustainable urban drainage systems (SUDSs), which mimic nature to manage stormwater runoff and provide other services to the urban environment. SUDSs are recognized as one of the main NBS techniques to improve urban resilience regarding stormwater management. These techniques can also be found with different designations, such as low impact development (LID), best management practices (BMPs), and green infrastructures. In this sense, an integrated approach of urban water management that incorporates a SUDS as a fundamental component is the Water Sensitive Urban Design, originate and widely applied in Australia. This approach to urban planning and design aims to integrate in the urban design the various disciplines of engineering and environmental sciences associated with the provision of water services [11].

To date, several studies were developed focused on the analysis of the resilience and sustainability enhancement based on SUDS implementation [12,13]. In the UK water sector, SUDSs are increasingly promoted in order to enhance flood resilience in urbanized areas and its application to increase resilience has also been studied [14,15]. For example, an approach adopted to quantify the cost-effectiveness of resilience measures and integrative and adaptable flood management plans was proposed [16].

The European Research and Development Program promotes a large number of projects related to NBS to increase knowledge and to create technical, political and other conditions for cities renaturalization. Improving risk management and resilience, using nature-based solutions, represents one of the mains goals of the EU Research and Innovation agenda [9]. These R&D projects will analyse several objectives and perspectives, as the improvement of regulatory instruments, the increase of the natural capital through NBS or the capacity to obtain a more sustainable and resilient urban ecosystem. In the context of urban resilience, some NBS studies were carried out focusing on some ES enhancement or on specific challenges, such as urban heat island mitigation [17,18], air quality improvement, climate mitigation and adaptation [19,20], and water quality improvement [21], among others.

Public participation is becoming increasingly embedded in the decision-making processes [22]. In this sense, several studies highlight the need to ensure a broader stakeholders' engagement in the development and implementation of assessment tools [23]. The development of the assessment process with stakeholders' collaboration promotes their empowerment and enhance their role in decision-making processes [24]. Regarding to the assessment process, stakeholders help to highlight weaknesses, to prioritize interventions and to identify the assessment tools adequacy to diverse locations. Stakeholders networks on NBS design, planning, and implementation are essential to ensure the transference of successful approaches between countries, communities and case studies [25]. Several available assessment frameworks include the stakeholders' participation in the development and implementation processes [26–28].

Currently, there is a need to analyse the NBS contribution to urban resilience and to develop tools that demonstrate the long term value of these solutions [29]. Several frameworks to assess resilience are being developed, such as the RESCCUE Resilience Assessment Framework (RESCCUE RAF) [26], the Disaster Resilience scorecard for cities [27], the Arup and Rockefeller city resilience framework [28] and the USEPA framework [30], among others.

Based on the review of the available resilience assessment frameworks (RAFs), the relevant *attributes* for resilience assessment were identified [31]. From this analysis, an RAF needs to i) propose a multi-dimension methodology that includes subjective and objective information, allowing us to measure urban resilience in one scale; ii) identify resilience objectives and criteria; iii) use qualitative and quantitative metrics addressing performance, cost and risk; iv) define reference values and a final resilience assessment; and v) identify the urban resilience capabilities associated with the proposed metrics. Additionally, there is a need for the RAF to consider and to allow the assessment of short- and long-term changes [30].

Regarding specifically the NBS for stormwater management and control, some assessment frameworks have already been developed, focusing on assessing NBS effectiveness in the face of climate change [32], supporting the design and impact assessment of the NBS for climate resilience [25] and to specific urban challenges, such as green space management or air quality [33]. Even though the NBS assessment frameworks are not directly focused on urban resilience, they may support a specific assessment framework focused on NBS contribution to urban resilience. To date, a comprehensive assessment approach has not been published to assess the contribution of NBS to urban resilience.

In this sense, among the several projects analysed, common concerns and knowledge gaps relevant to the development of a specific RAF for NBS were identified. Based on this analysis, an appropriate RAF for NBS should assess the following *aspects*: (i) social, environmental, economic, and governance dimensions; (ii) spatial and land use planning at the city level; (iii) service and infrastructure management; (iv) potential capabilities to provide ecosystem services (ES) and to enhance natural capital and biodiversity; (v) impacts on the surrounding area; (vi) infrastructure implementation and design, including adequate monitoring and maintenance processes; (vii) infrastructure performance under normal and stressing condition, considering acute shocks and continuous stresses; and (viii) infrastructure interdependencies with other urban services.

The main objectives of this paper are to present the methodology adopted for the construction of an RAF for NBS, as a specific RAF to evaluate the NBS contribution for urban resilience, and the stakeholders' validation, with focus on the analysis of relevance and applicability of metrics to cities. The main innovative contribution of this work is to propose a multidimensional and comprehensive RAF to assess the NBS contribution for urban resilience, focused on NBS for stormwater management and control. The proposed framework, driven by resilience objectives and assessment criteria, aims to integrate the *attributes* identified for urban resilience assessment and the relevant *aspects* for the NBS evaluation.

2. Methodology

2.1. Construction of a Resilience Assessment Framework for NBS

A new methodology for the construction of a specific assessment framework to evaluate the NBS contribution to urban resilience, with focus on solutions for stormwater management and control, is presented. The specific NBS considered in the RAF are the following: infiltration basins, green roofs and walls, vegetated swales, infiltration trenches, and porous pavements. This methodology allows to develop a multidimensional and comprehensive RAF that considers a broader definition of urban resilience. The methodology considers objective and subjective information and allows resilience to be measured on a single scale. As previously mentioned, urban resilience is defined as a city's ability to absorb disturbances, learn from the past, adapt, transform and prepare for the future. In this sense, the RAF considers five *capabilities* of a resilient city—namely, absorb, learn, adapt, transform, and prepare.

The proposed methodology is based on the performance assessment structure proposed by the ISO 24500 standards [34–36] for water supply and wastewater system management. The ISO 24500 structure is grounded on the definition of objectives, criteria and metrics. In the proposed methodology, resilience objectives aim to consider the several NBS contributions to urban resilience and the criteria allow to evaluate several aspects or points of view of the RAF objectives. Metrics are parameters or functions used to assess the criteria. In order to facilitate the RAF application, objectives were further grouped into two main dimensions.

The RAF seeks also to ensure the alignment with asset management, taking into consideration the fundamentals of value of the assets, leadership in service provision, assurance of alignment in the organization and of resources for effective implementation of a plan, along with the RAF application in the short and long term [37]. These conditions are incorporated in metric´s definition. The main *attributes* for an adequate urban resilience assessment (e.g., metric´s reference values ought to be defined) and the main *aspects* to be evaluated in the NBS (e.g., infrastructure management), identified in the literature review [31], are also considered.

The development of the RAF was performed in five main steps—i) identification of the urban resilience dimensions in the RAF; ii) definition of objectives, criteria, and metrics (O-C-M); iii) validation of the O-C-M of the RAF; iv) definition of reference values for each metrics; and v) consolidation of the RAF. The focus of this paper is on the methodology's first four steps.

2.2. Step 1: Identification of the Urban Resilience Dimensions in the RAF

Based on the existing literature review, the main areas that contribute to urban resilience (e.g., social and environmental areas) and the several aspects for an appropriate NBS assessment were identified (e.g., impact on the surrounding area). The main areas identified as well as *aspects* for NBS assessment were incorporated into resilience dimensions. Dimensions were also defined in order to combine similar levels of assessment. Two resilience dimensions were identified in the RAF. The first dimension addresses the assessment of resilience at the city level, and the second dimension is focused on the assessment of resilience at NBS level.

2.3. Step 2: Definition of Objectives, Criteria and Metrics

In the second step, urban resilience objectives, criteria and metrics were identified. Resilience has to be a tangible concept that cities are able to understand and measure, in order to build robust strategies and prioritize investments. The assessment of the RAF framework considers NBS performance by evaluating the contribution of these solutions at city, service, and infrastructure levels. In this way, it will be possible to identify how, when and where to act first in case of incipient resilience.

The resilience objectives highlight the several NBS contributions to urban resilience. The resilience criteria cover the aspects or points of view that evaluate the achievement of the objectives. The proposed metrics allow a clear assessment of the criteria, supporting the definition of explicit targets and monitoring of results. The use of quantitative and qualitative metrics allows the incorporation and evaluation of objective and subjective information, covering a more comprehensive definition of urban resilience.

The RAF includes metrics that assess performance, cost and risk of the NBS in accordance with the standard EN 752:2008 [38]. In metrics' definition, the related urban resilience capabilities (e.g., to be prepared) are identified. The metrics determination can resort to data from different sources and complexity, allowing the RAF application by cities with different information maturity. The RAF includes metrics with three levels of complexity—based on the existing data in the city (data based), based on a procedure defined for specific metrics (procedure based), or based on results from a mathematical model (model based). The method for metric determination and the specification of the required information was defined in this step.

2.4. Step 3: Validation of the Objectives, Criteria, and Metrics of the RAF

In this step, the RAF was submitted to stakeholders to identify knowledge gaps and improvement opportunities. The RAF validation includes the involvement and participation of stakeholders with different contexts, in a different resilience development level and with diverse NBS in the city, as water utilities or municipalities. The proposed dimensions, resilience objectives, criteria, and metrics were analysed with the stakeholders during working sessions. Metrics determination for participating cites and case studies is also carried in this step, taking into consideration the available information. In addition, a survey was conducted to determine the RAF metrics' relevance and the feasibility of application to their own cities.

The validation step includes (i) RAF submission to stakeholders to identify improvement opportunities and gaps, (ii) RAF application to participating cities, (iii) determination of metrics relevance and feasibility of application to cities, and (iv) complete RAF application to case studies.

Seven participating cities have contributed to the RAF validation steps—namely, Almada (Portugal), Coimbra (Portugal), Lisbon (Portugal), Porto (Portugal), Barcelona (Spain), Bristol (the United Kingdom), and Vancouver (Canada). The participating cities present different challenges regarding urban resilience and NBS. The participation of cities allows to validate the RAF taking into consideration different international and urban context, city dimension and management, NBS management (e.g., private, public), social involvement, and awareness, among other factors. Stakeholders from water utilities, municipal council and private organisation participated in the working sessions. A total of eight organizations validated the RAF.

2.5. Step 4: Definition of Reference Values for Each Metric

Reference values for each metric were defined to assess the NBS contribution to urban resilience on a normalized scale. The definition of reference values was based on existing literature review, regulations, standards and available assessment frameworks. An overall assessment will be proposed to measure the NBS contribution to urban resilience.

Reference values allow metric´s classifications by means of a judgment (e.g., satisfactory or unsatisfactory performance). Comparing the results of a metric with its reference values allow to pinpoint the existing problems and to monitor the implemented solutions.

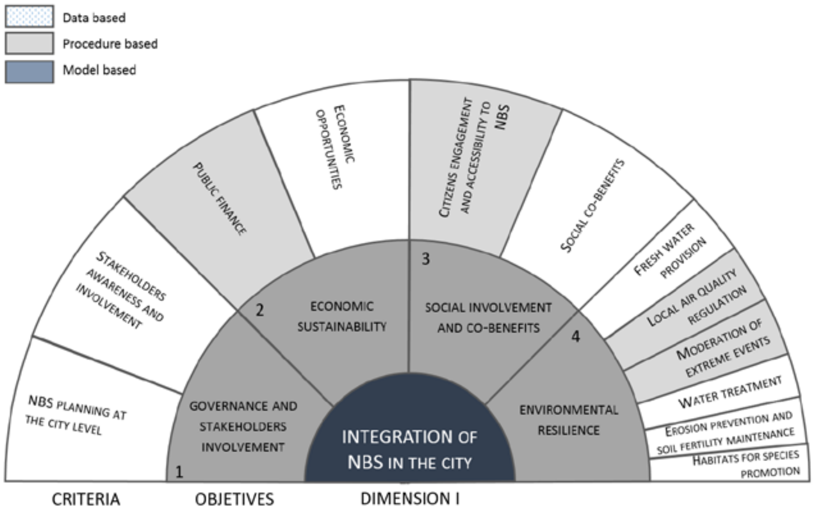
2.6. Complementary Profile

A complementary profile of the city needs to be established prior to the application of the methodology. This profile is intended to collect the characteristics of the city, of the NBS management service, and of the existing NBS under assessment. Specific information (e.g., urban context) is also detailed.

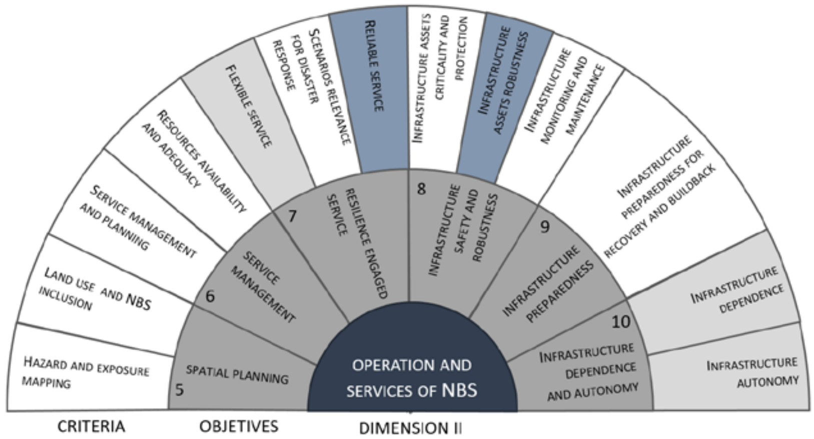
3. Resilience Assessment Framework for NBS

3.1. Overall RAF Structure

The RAF is structured in two resilience dimensions, namely "Integration of NBS in the city" (Dimension I) and "Operation and services of NBS" (Dimension II). A set of 10 resilience objectives is proposed in the RAF. Dimension I considers four objectives and 12 criteria. Dimension II considers six objectives and 13 criteria. A set of 71 metrics is proposed, divided in 34 metrics for Dimension I and 37 metrics for Dimension II. In Dimension I, 24 data based and 10 procedure based metrics are proposed. In Dimension II, 25 data based, three procedure based, and nine model based metrics are considered. Figure 1 presents the RAF dimensions, objectives, and criteria.



(*a*) *Dimension I—Integration of NBS in the city*



(*b*) *Dimension II—Operation and service of NBS*

Figure 1. Resilience assessment framework (RAF) objectives and criteria for (**a**) first and (**b**) second dimension, specifying the source of information required for metrics determination, by criterion.

3.2. Urban Resilience Dimensions (Step 1)

The resilience assessment proposal aims to evaluate the NBS contribution for urban resilience, focused on NBS for stormwater management and control. This RAF aims to support the diagnosis, decision-making, implementation, planning and management of the NBS and to identify solutions with potential to contribute to city resilience. Based on the identified *attributes* for resilience assessment and *aspects* for NBS evaluation, two dimensions are defined in the RAF.

Dimension I aims to assess the integration of NBS in the city governance and stakeholder involvement, economic sustainability and social involvement, as well as NBS contribution to the environmental resilience. The contribution of the NBS for urban resilience is assessed at the city level in this dimension.

Dimension II aims to assess the adequacy of the NBS to urban planning, the NBS functioning, regarding service management (e.g., service articulation between entities, allocation of financial and technical resources), its consequences in the surrounding area (e.g., ES improvement, flooded area, affected buildings), and the performance of the infrastructure. In this dimension, the NBS adequacy regarding urban, functional and physical components is assessed at the NBS level. Some objectives of the functional and physical components can be evaluated considering all NBS in the city or just some specific NBS.

3.3. Objectives, Criteria, and Metrics (Step 2)

The objectives aim to consider the several NBS contributions to urban resilience [20]. In this sense, the proposed resilience objectives consider the relevant governance, environmental, social and economic concerns and the main aspects of the city, service and infrastructure required to assess this contribution.

The resilience objectives of the Dimension I are focused on the NBS contribution to the social, environmental, economic, and governance aspects at the city level. These objectives aim to ensure city preparedness for governance, planning and financial aspects of the NBS. Also, these objectives aim to guarantee the NBS capabilities to promote green jobs, social co-benefits and ES, preparing the city for future impacts. The proposed objectives for this dimension are detailed as follows:

- Objective 1—Governance and stakeholders' involvement aims to ensure NBS planning at city level and the stakeholders' awareness and involvement. The criteria associated with this objective are the NBS planning at the city level and the stakeholder awareness and involvement. The criteria assess the governance component at city level, evaluating the adequacy of the NBS planning, the identification of the risk, identification of ES and protective infrastructure and the NBS alignment with ES. The proposed criteria also assess the stakeholders' engagement, the community involvement in the NBS processes (e.g., planning, decision making) and the existence of awareness campaigns.
- Objective 2—Economic sustainability aims to ensure financial capacity related to NBS and potential economic opportunities. The proposed criteria for this objective are the public finance and the economic opportunities. The criteria assess the existence of a specific budget for NBS, identify the monitoring and maintenance annual costs and assess the development of initiatives to promote the NBS in households. Concerning the economic opportunities, the criteria identify the creation of new green jobs, business and activities and tourism enhancement by NBS.
- Objective 3—Social involvement and co-benefits aims to ensure the citizen involvement, accessibility to NBS and social co-benefits. The proposed criteria for this objective are the citizens' engagement, NBS accessibility and the social co-benefits. The proposed criteria assess the citizens' engagement to NBS, the public accessibility and the NBS distribution. The proposed criteria also assess the main ES provision related to social co-benefits (e.g., urban heat island mitigation, health and well-being co-benefits).
- Objective 4—Environmental resilience aims to ensure the ES provision from NBS, relating to the environmental component. The proposed criteria for this objective are the fresh water provision, the local air quality regulation, the moderation of extreme events, the water treatment, the erosion prevention and maintenance of soil fertility and the habitats for species promotion. The capabilities of the NBS to provide ES are evaluated.

The resilience objectives of the Dimension II pretend to ensure the adequacy of the spatial planning and both service and infrastructure management at the NBS level. These objectives question the preparedness and adaptation of the urban planning and the integrated service management to NBS. In this sense, an adequate integration of these solutions in the risk identification, land use planning, and city policy are aimed at. Furthermore, these objectives aim to assure the capability of the city to absorb disturbance, transform itself and prepare for future scenarios, based on the existing NBS. The proposed objectives for this dimension are detailed as follows:

- Objective 5—Spatial planning aims to ensure hazard and exposure mapping and NBS identification in land use planning and risk areas at city level. The proposed criteria for this objective are hazard and exposure mapping and land use and NBS inclusion. These criteria assess the existence of updated hazard maps, the NBS identification on risk areas and their inclusion on the land use planning. Also, the NBS inclusion on major urban development and projects by policy is assessed.
- Objective 6—Service management aims to ensure the integrated management of the service and its articulation and the adequacy of competences and resources. The proposed criteria for this

objective are the service management and planning and the resources availability and adequacy. These criteria assess the existence of an integrated management for NBS and of an articulation and exchange of information between entities. Regarding available resources, the existence of adequate competences and of a specific entity in charge, with appropriate financial and technical resources, are also assessed.

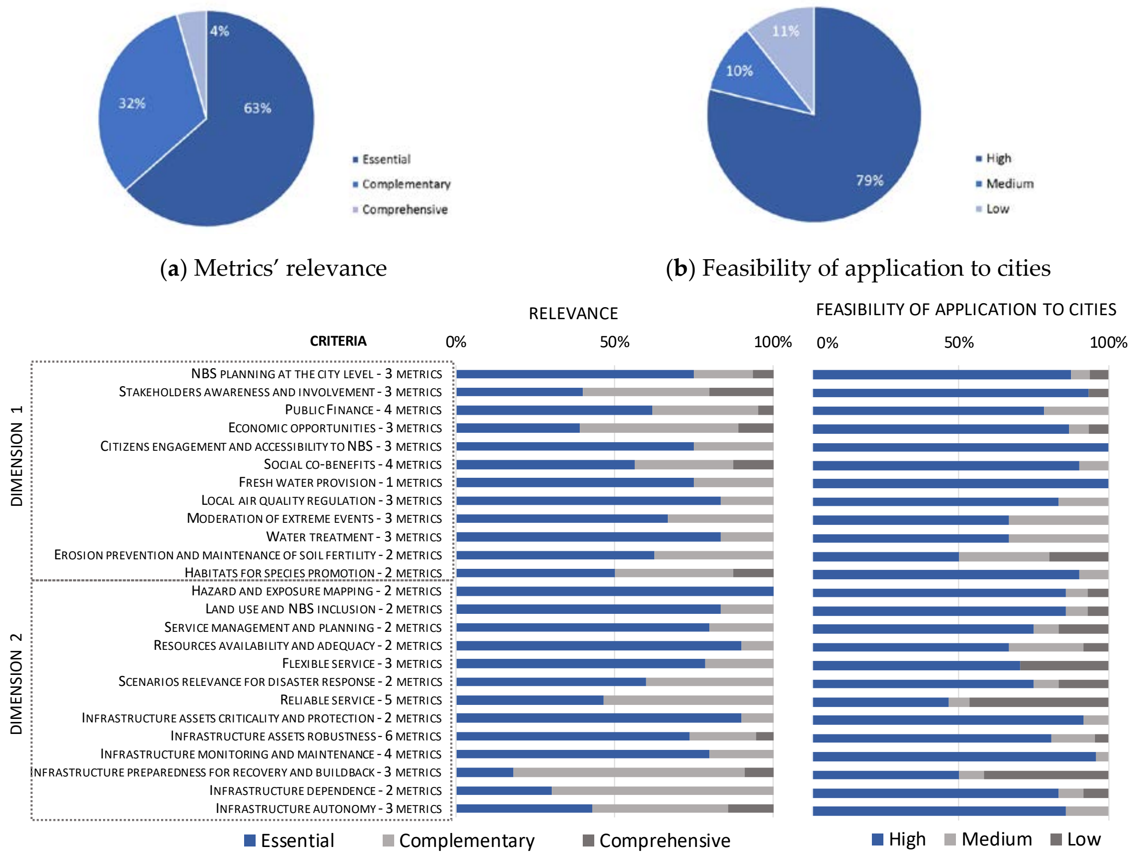
- Objective 7—Resilience engaged service aims to ensure service flexibility, disaster response and service reliability. The proposed criteria for this objective are the flexible service, the scenarios relevance for disaster response and the reliable service. As regards to flexible service, this criterion assesses the ES improvement and water reuse. Moreover, an adequate disaster response is assessed through the definition of relevant scenarios for heat wave, flooding and droughts. These criteria also assess the reliability of the service by minimizing the impact in the surrounding areas (e.g., flooding, critical location).
- Objective 8—Infrastructure safety and robustness aims to identify the criticality of the infrastructure and ensure the infrastructure assets' robustness, monitoring and maintenance. The proposed criteria for this objective are the infrastructure assets criticality and protection, the infrastructure assets robustness and the infrastructure monitoring and maintenance. The proposed criteria assess the identification of the critical components and the implementation of protective buffers. Regarding the infrastructure assets robustness, this criterion assesses the hydraulic and water quality performance regarding the infrastructure design conditions. Also, criteria assess the development and implementation of monitoring and maintenance plans, identified variables and other relevance aspects to be monitored and controlled.
- Objective 9—Infrastructure preparedness aims to ensure infrastructure preparedness to recover and buildback after a disruptive event. The proposed criterion for this objective is the infrastructure preparedness for recovery and buildback, which assess the infrastructure preparedness in the face of short and long-term changes, by addressing the impacts related to acute shocks and to continuous or chronic stresses.
- Objective 10—Infrastructure dependence and autonomy aims to identify the dependencies between other urban services and NBS infrastructure and the NBS autonomy. The proposed criteria for this objective are the infrastructure dependence and the infrastructure autonomy. In this sense, the criteria assess NBS dependencies from other services, the infrastructure of other services dependent on NBS, and the identification of the NBS infrastructure´s autonomy.

In order to allow for an objective assessment of each criterion, specific metrics were defined, including both quantitative and qualitative metrics. Metric selection seeks to properly evaluate the proposed criteria, taking into consideration that the metrics are interrelated. It is necessary to understand how they provide comprehensive information on the resilience maturity. The determination of the metrics in the Dimension I presents a higher feasibility of application, since most are data based and only some metrics are procedure based. The Dimension II presents greater complexity because it is necessary to develop a mathematical model of the NBS's hydraulic behaviour for proposed model-based metrics. Due to the high number of proposed metrics, they cannot be detailed in this manuscript. All objectives, criteria and corresponding metrics are supplied in the supplementary material (Table S1).

3.4. Validation of the RAF (Step 3)

RAF validation by the stakeholders provide the opportunity to contribute to adjust metrics' definition, to identify relevant sources of information for metrics' determination and test the assessment approach adequacy to different development levels of urban resilience. With this approach, stakeholders' contributions allow to consolidate the RAF, particularly, the proposed metrics and reference values.

This section presents an analysis of the metrics' relevance and feasibility of application to cities based on the stakeholders' opinion. According to [39], metrics' relevance was classified considering three levels—(i) essential, which should be integrated in the assessment of any city (essential for all cities); (ii) complementary, when the assessment corresponds to an intermediate level; and (iii) comprehensive, when the purpose is to make an in-depth assessment of the city. According to the feasibility of application, metrics were classified as high, medium, and low feasibility. Figure 2 presents the responses to metrics relevance and feasibility of application to cities, aggregated at the criterion level. Detailed responses for each metric are presented in Appendix A.



(**a**) Metrics' relevance (**b**) Feasibility of application to cities

(**c**) Responses to metrics relevance and feasibility of application to cities, aggregated at criterion level

Figure 2. Stakeholders' opinion regarding metrics' relevance and feasibility of application to cities.

Considering an overview of the metrics relevance, 63% and 32% are considered essential and complementary, respectively (Figure 2a). Only 4% of the metrics are classified as comprehensive. In terms of the feasibility of application, 79% and 10% of the metrics are considered to have high and medium feasibility application to cities, respectively (Figure 2b). Nevertheless, 11% of the RAF metrics are considered with low feasibility of application. The responses to metrics relevance and feasibility of application to cities, aggregated at the criterion level (Figure 2), confirm the conclusions obtained for the overall results, aggregated for the whole RAF (Figure 2a,b).

These results highlight the relevance of the selected metrics and, consequently, the assessment criteria defined in the resilience assessment proposal. In addition, the stakeholders' opinion regarding the feasibility of application provided the opportunity to identify which metrics are more suitable for a city depending on its resilience development level. In this sense, the stakeholders' opinion supported the selection of metrics to be considered in the RAF according to different resilience development levels. Recommendations will be further proposed in setting a tailored roadmap for the RAF application to the city with a preselection of metrics depending on the city´s resilience development level.

3.5. Reference Values (Step 4)

The classification of the metrics' result is made by associating each answer to a resilience development level, related to the reference values. The metric results are classified as (i) incipient (non-existent or at early stage of development); (ii) progressing (significant steps have already been taken); and (iii) advanced (consolidated results). The assessment of each metric is made according to reference values, defined from an extensive literature review on each metric. A resilience development level between 0 and 3 is then assigned, based on reference values, namely (i) incipient [0, 1], progressing [1, 2], and advanced [2, 3, 26].

Given the RAF structure (Figure 1), the results of the metrics contained in each criterion might be averaged to a criterion resilience development level, and further on, upwards to an objective and then to a dimension development level. Table 1 presents examples of three metrics, their reference values and the set of references used to support them.

Table 1. Examples of data, procedure, and model-based metrics and corresponding reference values proposed in the RAF for nature-based solutions (NBS).

Objective	Criterion (Metric Type)	Metric	Reference values	References
Social involvement and co-benefits	Citizens engagement and accessibility to NBS (DB*)	NBS distribution Are NBS scattered in the city?	3) Yes, NBS are scattered in the city, existing one or more NBS in each neighbourhood; 2) Yes, NBS are partially scattered in the city but they don't exist in every neighbourhood; 1) No, a significant number of NBS (with an area higher than 0.25ha) are concentrated in a few location or 50% of NBS area corresponds to one NBS;	[25] [40] [41] [42]
Environmental resilience	Local air quality regulation (PB)	Carbon sequestration and storage Is a carbon sequestration and storage increase expected due to NBS implementation?	3) Yes, above 60 t/ha; 2) Yes, between 10 and 60 t/ha; 1) Yes, less than 10 t/ha; 0) No.	[43] [44] [45] [46] [47] [48]
Resilience engaged service	Reliable service (MB)	Flooded area [Maximum flooding area, related to stormwater drainage problems / area of NBS urban catchment] x 100	3) No flooded areas; 2) Less than or equal to 2.5% area is flooded; 1) More than 2.5% and less than 5% area is flooded; (0) More than or equal to 5% and less than 10% area is flooded.	[27] [49] [50]

* DB: Data based, PB: Procedure based, MB: Model based.

4. Conclusions

This paper presents the methodology adopted for the construction of a RAF to assess NBS contribution to urban resilience and the developed structure of the RAF for NBS, focused on solutions for stormwater management and control. This resilience assessment proposal ensures the evaluation of the main *attributes* of the urban resilience and the relevant *aspects* for the NBS evaluation. The RAF aims to support NBS diagnosis and to assist decision-making in its planning, implementation, and management. Also, this framework allows to identify NBS with potential to contribute to city resilience.

The determination of the metrics relevance and feasibility of application to cities is a fundamental step in the validation step. Considering the metrics relevance, the stakeholders' opinion allowed to conclude that most metrics are considered essential for the assessment of the NBS contribution for urban resilience. Regarding the feasibility of application, a higher variability in the stakeholders' responses was obtained. As expected, procedure and model based metrics were labelled as medium or low feasibility of application, mainly at the service and infrastructure level.

In this sense, the criteria identified as with lower feasibility of application correspond to the following criteria: (i) flexible service, (ii) reliable service, and (iii) infrastructure preparedness for recovery and buildback. Regarding the flexible service criterion, the lower feasibility of application is due to the lack of awareness of ES and the difficulties related to the use of the NBS retained water for other purposes, at city level. From another hand, the lower feasibility of application of the reliable service and infrastructure preparedness for recovery and buildback criteria is because metric determination is carried out based on a mathematical model.

The stakeholders' participation highlighted the relevance of each metric and criteria defined in the RAF. Stakeholders' opinion allowed to identify the RAF adequacy to diverse city maturity levels and helps to select adequate metrics for the cities according to the urban resilience development level. Based on this analysis, the consolidation of metrics definition and required data will be carried out.

The RAF consolidation will be carried out after its complete application to the case study. In this step, the metrics' definition and the required information will be verified. In this sense, future work will focus on the consolidation of the RAF and on the proposal of a roadmap for the RAF application to any city.

The RAF application should follow the proposed roadmap and consider pre-selected metrics. The pre-selected metrics and the required information depend of the urban resilience development (incipient, progressing, advanced). For example, only for cites with advanced urban resilience development the model based metrics will be determined, and, consequently, the information provided by the mathematical model, which is more detailed and difficult to obtain, will be required.

The determination of the RAF will be carried out by a multidisciplinary team composed by human resources of the entities in charge of NBS management, stormwater management services and green space management. The RAF can be applied to assess the contribution to urban resilience of all existing NBS in the city, a group of NBS or a specific NBS. For this reason, the NBS under assessment should be identified in the complementary profile.

Supplementary Materials: The following are available online at http://www.mdpi.com/2071-1050/12/6/2537/s1. Table S1. Objective, criteria, and metric of Dimension I "Integration of NBS in the city".; Table S2. Objective, criteria, and metric of Dimension II "Operation and service of NBS".

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Appendix A

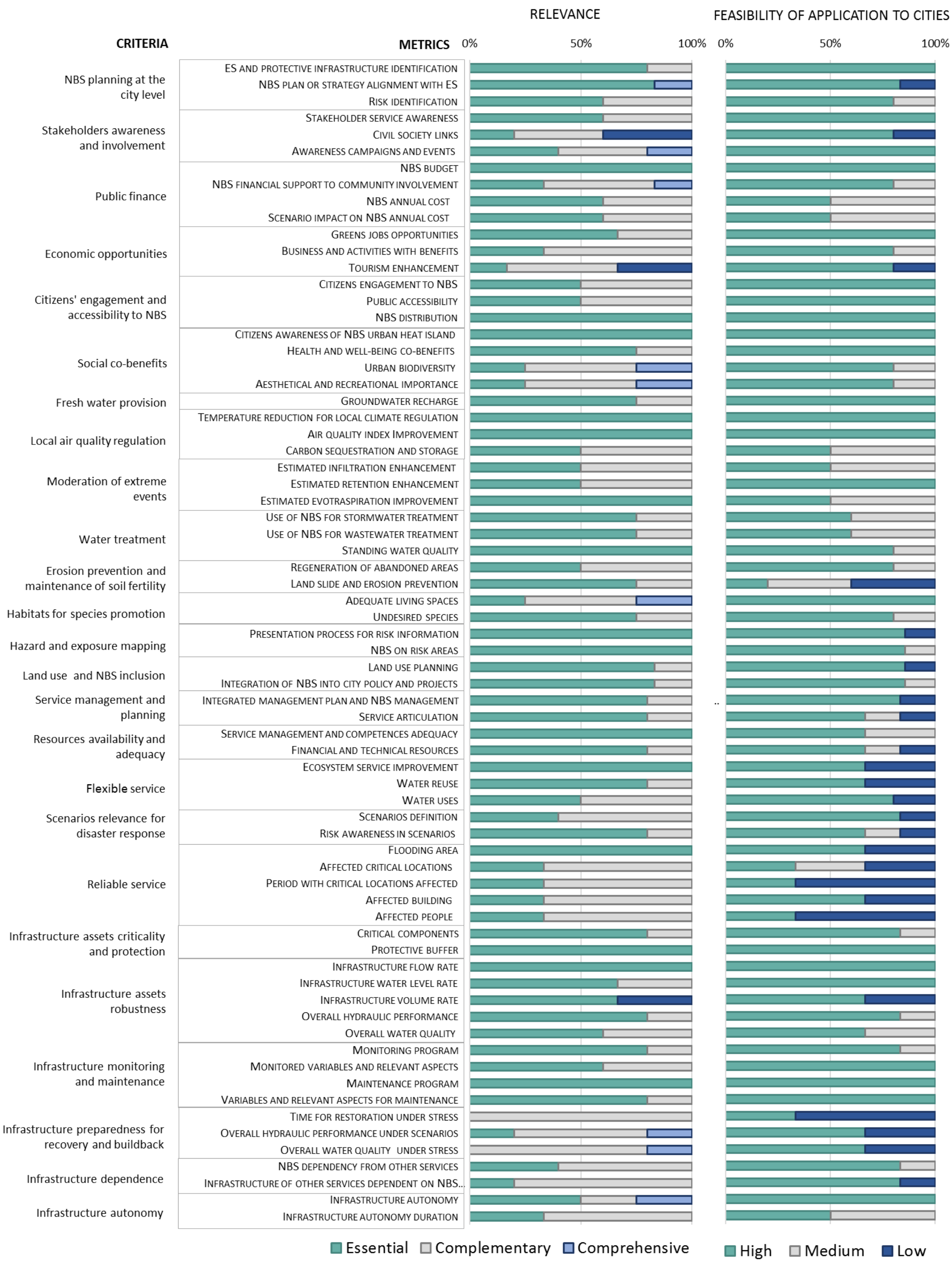

Figure A1. Stakeholders' opinion regarding the metrics relevance and feasibility of application to their own city at the metric level.

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