Innovating Urban Systems Through Nature-Based Solution for a Circular Economy Enhancement: A General Framework

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Abstract. Cities and communities are worldwide facing several issues and challenges related to global issues concerning climate change, as well as local conditions. Urban systems are the core and the key elements to pursue the transition to a more sustainable, resilient, and circular development. For this purpose, Nature-Based Solutions (NBS) are currently encouraged as technologies and strategies to support cities and communities in their transition towards sustainable and resilient development. Moreover, NBS have been recently coupled with the objective and challenges of implementing the Circular Economy (CE) paradigm in urban systems. Therefore, this article explores the relationship between NBS and CE paradigm implementation in urban systems, to highlight if this topic is discussed in literature, as well as if the evaluation of NBS with CE perspective is explored. For this purpose, this study analyses the main NBS catalogues and frameworks. The performed analysis recognizes some lacks and criticalities according to these aspects. Therefore, this research proposes a framework to collect NBS according to the scale of implementations and to provide suitable evaluation tools to assess the generated multidimensional impacts with a CE perspective. The operating principle of this framework is illustrated with a focus on urban agriculture, which has been selected according to its emblematic role in implementing the CE paradigm in urban systems. Moreover, the potentiality of the proposed framework has been discussed, highlighting the possible practical implications for practitioners and Decision Makers (DMs).

Keywords: Nature-Based Solution (NBS) · Circular Economy · Urban agriculture

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1 Introduction

Worldwide, cities, territories and societies face a wide range of multidimensional challenges related to climate change, natural disasters, and specific local conditions. These stresses and pressures ranging from population growth, economic crisis, environmental stresses, the availability of energy resources and the accessibility to affordable and safe food [1]. Moreover, current conditions will be made more and more extreme by the projected growth of urbanization, with the increase of the urban population by 68% by 2050 [2].

Furthermore, cities are at the same time the major cause of climate change in terms of urbanization, resource consumption and pollutant production, as well as the centers through which to intervene for moving towards the urgent transition to a sustainable, circular, and resilient approach of the management of natural resources such as water, food, and energy [3]. To pursue the goal of a transition to a sustainable, circular, and resource-resilient approach, many concepts and actions have been introduced, from the paradigm of "sustainable development" [4] to the concept of "urban resilience" [5], from the introduction of the Sustainable Development Goals (SDGs) [6], to the implementation of the Circular Economy model [7–10].

Sustainable development has been defined by the Brundtland Report (1987) [4] which declares that "*the sustainable development is the development that meets the needs of the present without compromising the ability of future generations to meet their own needs.*"

The concept of urban resilience has many definitions, however, it can be described as "*the ability of an urban system and all its constituent socio-ecological and socio-technical networks across temporal and spatial scales to maintain or rapidly return to desired functions in the face of a disturbance, to adapt, to change and to quickly transform systems that limit current or future adaptive*"[1] [11].

The concept of Circular Economy (CE) can be addressed as an evolving "umbrella" concept which encompasses several definitions [8, 12]. However, it is possible to state that the CE paradigm aims to pursue an economic growth model which limits the consumption of new resources and reduces environmental impact (to see the used definition of CE for this dissertation, please see Sect. 2). Therefore, implementing the CE paradigm presupposes and imposes an urgent change of the modality through which human society interconnects with nature [13].

On the other hand, the Nature Based Solutions (NBS) can be described as "*nature-inspired and nature-supported, cost-effective solutions that provide simultaneous environmental, social, and economic benefits and help build resilience. Such solutions bring more nature, natural and diverse features and processes to cities, landscapes and seascapes, locally adapted and resource-efficient*" [14, 15].

Based on their characteristics, NBS have been therefore coupled with the CE concept as suitable strategies and technologies for implementing and achieving this paradigm in cities [12, 13, 16, 17]. According to this scenario, this article explores the relationship between NBS and CE in urban systems, focusing on the NBS assessment topic.

[1] Meerow et al., 2016, p. 39.

Therefore, the research questions addressed by this research can be summarized as follows:

1. $\boldsymbol{Q_1}$ "Is the relationship between NBS and CE clearly described and discussed in the literature?"
2. $\boldsymbol{Q_2}$ "How the evaluation of NBS within the CE perspective has been addressed? Are there some frameworks which proposes suitable evaluation methods or provide guidelines for this evaluation demand?".

To answer to these research questions, a methodological framework structured into two phases have been followed. Firstly, a literature review has been performed to describe the concept of CE and identify the definition to use in this research, according to the linkage with NBS (Sect. 2), as well as a focus the topic of CE in urban context (Sect. 2.1) and defining NBS and to highlight the aspects in common with CE (Sect. 3). Secondly, this research analyses the existing NBS catalogues and frameworks to address the declared research questions (Sect. 4). Therefore, according to the recognized lacks, this article proposes a methodological framework to identify NBS for CE implementation in urban systems within the indication of the suggested evaluation models to give guidelines to researchers and practitioners to overcome the current issues (Sect. 5). In conclusion (Sect. 6), this paper discusses the suitability of the proposed framework within its operative implications, as well as underlines the preliminary stage of the research describing the following development.

2 The Concept of Circular Economy (CE)

This section generally describes the peculiarities of the concept of CE, highlighting the key features related to the topic of the dissertation. It is not intended to deal with the concept of CE in its entirety and its complex literature review.

The concept of CE can be considered as an evolving umbrella concept encompassing several definitions [8, 12] to pursue an economic growth model that limits the consumption of new resources and reduces environmental impact.

However, despite the complexity and multiplicity of definitions, it is possible to identify the three founding principles of the circular economy paradigm, as defined by the Ellen MacArthur Foundation [18]:

1. regenerating natural capital;
2. keeping resources in use;
3. eliminate waste externalities.

Furthermore, based on the analysis of various definitions provided by the literature [8], it is possible to clarify the operational objective of the CE paradigm. In particular, this research leans on the definition proposed by Langergraber and colleagues [16] to address the CE challenges and principles, "*the circular economy involves the implementation of an economic system aimed at minimizing waste and making the best use of resources. In a circular system, resource inputs and losses of waste, emissions and energy are minimized by slowing down, closing, and tightening energy and material loops*".

Therefore, as above underlined the implementation of the CE paradigm presupposes and imposes a shift of the approach through which human society interconnects with

nature. Furthermore, the literature identifies different levels through which CE can be implemented to prevent resource depletion and facilitate sustainable development, or rather [19]:

1. micro-level (businesses and consumers);
2. meso-level (symbiotically integrated economic agents);
3. macro-level (cities, regions, and governments).

Therefore, it can be addressed that achieving this circular model requires cyclical and regenerative environmental innovations in the way society produces and consumes [7, 16, 20, 21].

2.1 The Paradigm of Circular Economy in Urban Systems

As mentioned in the previous section, this research mainly focuses on the implementation of CE in urban systems, therefore it addresses the macro-level of implementation within the city scale.

Defined the main principles and described what it is intended here for the CE paradigm, it is here necessary to describe what the concept of circular city means [22–24]. Also in this case, this section is not intended to deal with the concept of circular city in its entirety and its complex literature review. It aims at providing the mail pillars of this concept, to support this dissertation.

It can be generally addressed that CE is viewed as a mechanism that helps cities shift from linear to circular resource management [13, 23]. Therefore, it can be addressed that the circular city model recognizes the importance of organizing the city's systems in an analogy to the organization of natural systems [13, 23].

Furthermore, by the literature is possible to identify the main challenges of implementing the circular economy paradigm in urban systems [23, 25], these can be grouped into two main categories:

1. Preserving natural resources by reducing their import;
2. Minimizing waste production by using resources in cycle.

3 Nature-Based Solution for Circular Cities

To better understand the relationship between NBS and the CE paradigm, it is necessary to describe what it is intended for NBS. As briefly reported in Sect. 1, NBS can be defined as solutions inspired by nature with the capacity to contemporary address social, economic, and environmental challenges of cities [26]. Therefore, NBS are encouraged as technologies and strategies to support cities and communities in their transition towards sustainable and resilient development [26–29].

Furthermore, NBS are aligned with other multidimensional concepts closely related to the CE concept, such as the ecosystem approach, which promotes the integrated management of natural resources such as soil, water and biodiversity, as well as their conservation and sustainable use [16, 30, 31]. As well as, the implementation of NBS aims at maximizing the interaction between nature, society and the economy [27, 31, 32].

Therefore, NBS emerge as important implementation strategies and technologies for achieving and operationalizing the principles and challenges of the CE paradigm [13], supporting the management of resources in a circular perspective.

Furthermore, to emphasize and legitimize this statement, it is possible to cite a challenge reported by the European project ThinkNature, or rather: "*One of the most important aspects of NBSs is to consider them in a circular economy and urban innovation systems. That is, not to simply privilege them, but to see them in the light of an integrated urban development*" [17].

According to the literature [13, 25], it is also possible to state which urban circularity challenge can be addressed through NBS implementation in urban systems:

- Restore and maintain the water cycle;
- Water and waste treatment, recovery and reuse;
- Nutrient recovery and reuse;
- Material recovery and reuse;
- Food and biomass production;
- Energy efficiency and recovery;
- Building system recovery.

To better underline the increasing interest in implementing NBS in urban systems to implement the CE paradigm, some European projects and initiatives are here listed. The main projects are:

1. "COST ACTION - Implementing Nature-Based Solutions (NBS) for creating a resourceful circular city"[2]. This action aims to test that the hypothesis of implementing NBS to efficiently manage nutrients and resources in the urban context should head to a sustainable, resilient, and healthy urban environment. According to this objective of closing the resources cycle within urban metabolism, the project focuses on five dimensions: (1) built environment, (2) urban water, (3) resource recovery, (4) urban farming, and (5) socio-economic impact.
2. "CAP NET – Water knowledge for all"[3]. This project proposes an online course entitled "NBS for creating circular cities"[4]. This class aims to provide the required knowledge about creating a circular city by implementing NBS. It gives pillars about resource flows and management in cities, selecting the appropriate NBS for managing resources, and it provides some implementation examples to help understand this complex domain.

These examples demonstrate the increasing interest and efforts in implementing NBS to achieve the CE paradigm at the urban level. Therefore, it can be addressed that by incorporating NBS, cities can create regenerative green urban spaces, sustainable buildings, and prospering communities, while minimizing resource imports and waste production [13, 25].

[2] https://www.cost.eu/actions/CA17133/ (last seen on May 7, 2024).
[3] https://cap-net.org/ (last seen on May 7, 2024).
[4] https://cap-net.org/circularcities/ (last seen on May 7, 2024).

4 Analysis of NBS Existing Catalogues and Frameworks

As underlined before, to answer to the above-mentioned research questions Q_1 and Q_2, the existing NBS framework and catalogues have been analyses to underline both strengths and weaknesses concerning the research demands.

In literature, several catalogues and frameworks have been provided by many European projects. The study proposed by Stessens and colleagues (2022) [33], proposes a complete overview of the main NBS catalogues developed within different European projects.

In this context, the main listed catalogues have been analyzed and compared which are [33]:

- UNaLab: NBS technical handbook [34];
- ThinkNature – Nature Based Solution Handbook (THK) [35];
- Urban GreenUP – NBS Catalogue [36];
- CLEVER CITIES Catalogue NBS [37];
- Klimatek project [38].
- Nature4Cities [39];
- Naturvation [40];
- URBiNAT [41].

Table 1 analyses and compares the selected catalogues according to these criteria:

1. Presence in the catalog of NBS definition;
2. Reference and dissertation about the linkage between NBS and CE paradigm and challenges in urban systems;
3. Guidelines to assess multidimensional impacts generated by NBS implementation.

According to the developed analysis (Table 1), it is possible to address that the information provided by NBS catalogues cannot be considered homogeneous. Firstly, the description of what is intended for NBS is not provided in every catalogue. It is clearly discussed only in four of the considered catalogues, or rather (1) UrbanGreen UP, (2) Klimatek project, (3) nature4Cities, and (4) Urbinat. Secondly, it is possible to state that most of the analyzed catalogues do not address the linkage between NBS and the CE paradigm and challenges in urban systems, despite the great attention to the topic as highlighted in Sect. 3 and by the performed literature review [42–47]. The catalogue provided by ThinkingNature is the only one that stresses this topic, underlining the importance of NBS as a strategy to implement CE paradigm in urban systems (please see the citation in Sect. 3). Thirdly, it can be addressed that information about NBS multidimensional impact assessment are not homogeneously and comprehensively given. More in detail, it is possible to underline that a few times economic impacts are not addressed and described at all, as in the cases of UnLab and Klimatek project. As well as, it can be pointed out that in most cases the multidimensional impacts are mainly qualitative assessed, without providing information about the applied evaluation methods.

However, in this context, it is necessary to highlight that Naturvation project analyses in-depth the topic of NBS multidimensional impacts assessment according to social, economic, cultural, and environmental dimensions [40]. Furthermore, it proposes methods to assess these impact though monetary terms, to give a comprehensive evaluation

Table 1. Analysis of the considered NBS catalogues and framework

Catalogue	NBS definition	Reference to NBS and CE	Information of impacts assessment			Ref.
			SOC.	ECO.	ENV.	
UNaLab	✗	✗	✓*	✗*	✓*	[35]
Think Nature (THK)	✗	✓	✓*	✓*	✓*	[36]
Urban GreenUP	✓	✗	✓*	✓*	✓*	[37]
Clever cities	✗	✗	✓*	✓*	✓*	[38]
Klimatek project	✓	✗	✗	✗	✓	[39]
Nature4Cities	✓	✗	✓*	✓*	✓	[40]
Naturvation	✗	✗	✓	✓	✓	[41]
Urbinat	✓	✗	✓*	✓*	✓*	[42]

Legend	
✓	present in the catalogue
✗	not present in the catalogue
SOC	social impacts
ECO	economic impacts
ENV	environmental impacts
*	the impacts are evaluated qualitative

[40]. However, Naturvation project does not provide evaluation method to assess NBS within CE perspective. On the other hand, the Nature4cities project proposes the Lyfe Cycle Assessment (LCA) and provides multidimensional indicators [39]. These methods could also be useful in the perspective of NBS assessment with a CE perspective.

According to the performed analysis, it is possible to state that no comprehensive and homogeneous description and classification of NBS are provided. As well as, the assessment of NBS multidimensional impacts in not in-depth discussed, within a main lack in addressing NBS within CE perspective. Therefore, it can be addressed that a framework that provides the basic background of NBS interventions and guidelines for the selection of evaluation tools suitable for the assessment of the multidimensional impacts generated by NBS with the perspective of the implementation of CE paradigm in urban systems is required.

5 The Proposed Framework

According to the above-mentioned lacks and the objective of this research, this section proposes and describes the general structure of a new collection framework of NBS intervention typologies. Furthermore, it is necessary to underline that the proposed framework is not presumed to be an overall and final framework, it aims at proposing the useful general structure to be further implemented.

The proposed framework aims to give information related to:

1. Scale of implementation. This information is considered fundamental to propose a categorization of NBS according to their scale of implementation. More in detail, three different scales of interventions have been identified (1) building scale, (2) neighborhood scale, and (3) municipal scale. This classification has been selected to identify to which scale different NBS interventions are referred and also to support the designing process;
2. NBS intervention typology. According to the scale of implementation, this framework can list different types of intervention. In detail, this section will be implemented by the collection of the provided information of existing NBS catalogues that need to be homogenized [34–41].
3. Evaluation methods. This section should provide information on the evaluation models that can be used to assess NBS with CE perspective, which is the point most highlighted as lacking in the previous analysis.
4. Source. This section lists the references of the main case studies in which the proposed evaluation methods are applied to give information and guidelines to apply them in other contexts.

Table 2 illustrates the general structure of the proposed framework with some examples of NBS interventions classified according to the scale of implementation.

Table 2. General structure of the proposed framework

Scale of implementation	NBS interventions	Evaluation methods	Sources
Building scale	Examples: green facades, green roofs		
Neighborhood scale	Examples: urban orchards, Regreening spaces between buildings		
Municipality scale	Examples: urban agriculture		

Table 3 illustrates one example to illustrate how the proposed framework works and how it can support the evaluation of NBS according to multidimensional impacts with the CE perspective. More in detail, urban agriculture has been selected to represent the functioning of the proposed framework according to its emblematic role in implementing the CE paradigm in urban systems, according to its capability to address several CE challenges, as underlined in Sect. 3 by describing the COST Action project [16, 48, 49].

Table 3 describes the NBS related to urban agriculture according to the scale of implementation that is the municipal scale, according to the fact that it can be implemented within different approaches according to the available space from traditional systems to vertical farming, to small decentralized systems such as shared neighborhood gardens [16, 44]. Moreover, the framework reports and proposes different evaluation methods to address and assess this NBS according to the CE paradigm in urban context. Moreover, the main references of the application of the proposed evaluation methods are reported to give suitable information about how to reply these evaluation.

Table 3. Scheduling of urban agriculture NBS according to the proposed framework

Scale of implementation	NBS intervention	Evaluation methods	Sources
Municipality scale	Urban agriculture	Life Cycle Assessment (LCA) Life Cycle Cost Analysis (LCC)	[50, 51]
		Multi-Criteria Analysis (MCA)	[52]
		Indicators-based model for stakeholders' perspective evaluation	[53]

According to this brief and practical example, it can be addressed the suitability and capability of the proposed framework to provide useful and operative information about the typology of NBS, their scale of implementation and how it is possible to assess them according to the CE perspective. This information can support in operative way researchers, practitioners, planners, and Decision Makers (DMs).

6 Conclusion

According to the increasing attention to NBS implementation strategy in urban systems [26], the present paper explores the relationship between NBS and CE paradigm implementation in urban systems [42–47], in order to address two research questions $\boldsymbol{Q_1}$ and $\boldsymbol{Q_2}$ (Sect. 1). For this purpose, this research developed a general literature review about the main considered concepts and it explores the main NBS catalogues developed within several European projects to analyze the provided information and guidelines [33].

From the performed analysis (Sect. 4) it has been possible some criticalities. First of all, catalogues and framework are not providing aligned and homogeneous information. As well as, many times the topic of NBS evaluation in briefly discusses and operative suggestion are not provided. Moreover, on the catalogue by ThinkNature [35] addresses the linkage between NBS and CE paradigm and challenges in urban systems, despite the great interest of this topic in the literature [13, 25, 43–47].

According to this state of the art, this research proposes the general structure of a new framework to recognize and collect NBS according to (1) scales of implementation,

(2) intervention NBS typologies, (3) evaluation methods within CE perspective, and (4) reference of developed case studies. The main objective of this framework is to collect in a unique framework the information provided by the existing catalogues [34–41]. More in detail, this essay illustrates the functioning of the proposed framework with the illustration of urban agriculture NBS, according to its emblematic linkage with CE paradigm implementation [16, 48, 49]. Moreover, by this example is possible to underline the operative implication that this framework should have in implementing NBS for CE achieving in urban systems. It can support planners, researchers, practitioners, and DMs in briefly categorising NBS according to their scale of implementations, as well as giving useful information and examples about how to assess them within CE perspective, to address this achievement.

However, it has to be underlined that this proposed framework is not to be presumed as comprehensively developed. It has to be considered as a starting point to collect information through homogeneity and a general overview of available evaluation methods to assess generated multidimensional impacts within CE perspective.

Therefore, the future development of the proposed research foresees the implementation of the proposed framework by collecting and describing other NBS to map all the considered scales of implementations to construct an operative tool that provides the basic and common knowledge to encourage interdisciplinary collaboration [54] between planners, architects, DMs, and local stakeholders for NBS designing for CE implementation in urban systems.

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