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A frame of understanding to better link nature-based solutions and urban planning

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ABSTRACT

Reinforcement of the concept of nature-based solutions in urban environments calls for their better introduction and linkage into urban planning. The paper is focused on the relationship between nature-based solutions and spatial realities, based on reciprocity among natural processes and urban patterns, emphasising the recognition of using and mimicking natural processes in urban environments. A classification framework as a form of knowledge aggregation is suggested. A matrix that simultaneously addresses the role of natural processes in nature-based solutions and the ability of such processes to deliver results for improving urban environments is proposed. Accordingly, there are three characteristic groups of solutions suggested, (1) those only using natural processes, (2) those using and mimicking natural processes and (3) those only mimicking natural processes, which implementation potentials are commented against four different types of urban patterns, to show what group of the nature-based solutions may best suit any type of spatial agglomeration. Beside green infrastructure as currently the most often addressed manifestation of nature-based solutions in cities, the paper reflects also on the physical processes as inevitable parts of nature. In relation to urban planning, sites and their characteristics are seen as a crucial aspect of nature-based solutions. The arguments are built upon exhaustive literature and case studies review, resulted in the matrix showing the matching relations among nature-based solutions and societal challenges aiming for better urban environment. Additionally, there are also sets of recommendations for bridging the policy-implementation gaps to bring nature-based solutions closer to urban planning, suggested.

1. Introduction

This paper builds upon a study conducted for the Ministry of the Environment and Spatial Planning of the Republic of Slovenia (Goličnik Marušić et al., 2021) to address the relationship between nature-based solutions (NBSs) and urban planning. The aim is to provide a better understanding of NBSs for the purpose of urban planning and establish NBS-related urban planning as a tool for creating climate-change-resilient, sustainable cities and towns that enable quality living.

The most used and well-known definitions of NBSs, set by the European Commission (European Commission, 2015), describe them as solutions based on (i.e. inspired and supported by or imitating) natural processes that address the current key socio-ecological challenges. Raymond et al. (2017a) show that these challenges often include climate change mitigation and adaptation, water management, green space management, improvement of public health and well-being, improvement of air quality and urban regeneration implementation. Although one of the first definitions of NBSs was put forward by the International Union for Conservation of Nature (IUCN; Cohen-Shacham et al., 2016), in prioritising nature conservation and management issues, the NBS concept goes beyond such traditional principles by simultaneously placing social, environmental and economic challenges, which is also reflected in recent IUCN documents (e.g. IUCN, 2020).

The number of published works on NBSs has significantly increased since 2016. Nesshöver et al. (2017) show that there are various interpretations and points of focus in the understanding of NBSs and that NBSs are more often understood and used as a spatial-development concept in research, policy and practice than employed in relation to concrete solutions. Although the European Commission promotes NBSs in various policy areas and strategies – as it recognises the potential of these solutions with regard to different strategic, research and

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innovation spheres and financial mechanisms (Davies et al., 2021) – the definition of NBSs is rather general, and there remain some inconveniences in the implementation of NBSs in urban planning practice. The European Green Deal (European Commission, 2019) specifically mentions NBSs in urban environments in relation to the impacts of climate change, while the EU Biodiversity Strategy 2030 (European Commission, 2020) highlights NBSs as a key instrument for climate change adaptation and mitigation as well as for greening cities. However, global and EU policies lack mandatory requirements for the concrete integration or designing of NBSs. Further, according to Li et al. (2021), a consensus regarding the conceptual links between NBSs and other concepts in the socio-ecological system has still not been reached.

1.1. NBSs in the urban planning context

In the urban planning context, several well-established approaches that use nature as a tool to address societal challenges are applied in practice; but their roles with respect to contributing to spatial solutions have not yet been precisely defined nor have specific solutions been addressed systematically. Currently, the interpretations of NBSs are often associated with ecosystem services (e.g. Castellar et al., 2021; Croeser et al., 2021; Vignoli et al., 2021), which consequently address NBSs in urban environments in terms of green spaces and green-infrastructure elements. Additionally, NBSs are increasingly being used for circularity challenges in cities, especially in urban water-cycle management (e.g. Langergraber et al., 2021), which, in addition to water infrastructure, directly relates to rough terrain and other (non-) hard-surfaced urban areas and their hinterland (i.e. elements of green infrastructure). Urban water management is becoming an increasingly crucial area (Langergraber et al., 2020; Nika et al., 2020) in which NBSs are being promoted as possible measures for applications such as ensuring natural runoff replication or closing material-flow loops.

However, the notion of mobilising nature and its processes as a principle of spatial and urban planning is not new. Chronologically speaking, such ideas have emerged every few decades and are usually linked to environmental issues. In the first half of the 20th century, discussions surrounding this topic arose due to rapid industrialisation, the effects of which critically manifested in the 1960 s. Addressing spatial planning dimensions, especially in the US, the approach employed by McHarg (1969), called ‘design with nature’, was one of the most influential. The author posited that the best way to occupy and modify landscapes is to plan and design the process with careful consideration of both the area’s ecology and the character of the landscape. In this way, he argued that our cities could be safeguarded against major natural hazards and become truly regenerative (or, in modern terms, truly resilient). The latter greatly resonates with the modern expectations of NBSs. Furthermore, McHarg (1969) believed that by working with rather than against the landscape’s powerful forces and flows, communities would gain an increasingly strong sense of place and identity, which is again reflected in the social dimension of NBSs as perceived today. Regarding the large scale, which is more relevant to the urban design of parks and neighbourhoods, similar conceptions were addressed by the so-called natural-garden concept that emerged in the second half of the 20th century (e.g. Le Roy, 1983). This concept follows a design principle based on native spontaneous vegetation growth and, therefore, in relation to modern NBSs, promotes the use of and respect for natural processes and support for increasing biodiversity. However, when this concept was introduced, it did not follow the full scope of NBSs because it did not define the term ‘nature-based’ as ‘inspired by, supported by or copied from nature’ (European Commission, 2015, p.4). The concept did not extend beyond the direct exploitation of green (living) nature.

Despite the recognised advantages, the fact remains that the NBS approach is still quite new, and NBSs have not yet been systematically integrated into spatial (and other sectorial) planning (Bush and Doyon, 2019; De Luca et al., 2021; Mendes et al., 2020). For example, The European Environmental Agency (EEA, 2021) shows that the scope of NBSs implemented in urban planning can cover the so-called individual elements (e.g. buildings, streets and car parks) and areas (e.g. neighbourhoods, settlements and enclosed urban areas), whereas the actual networks of NBSs and their common effects have not yet been addressed. Examples of individual elements include NBSs such as green roofs, vertical greening, grassed areas and pocket parks. A review of Oppla Case Studies (2021) revealed that most NBS examples correspond to this level and that most actions involve the creation of new ecosystems in existing urban areas or degraded areas. At the city level, in the context of spatial planning, NBSs are usually addressed in various documents that refer to either sets of implementations of specific types of NBSs (e.g. green roof), specific challenges (e.g. climate change adaptation, including sustainable urban drainage systems, green roofs and rain gardens) or various integrated visions in conjunction with the public investment funds for the creation of a resilient city.

1.2. Integration of NBSs into urban planning policies and practices

In this context, the challenge is associated with how to further elaborate on NBSs and their suitability and effectiveness with regard to solution provision, especially in terms of their applicability in specific urban contexts. In this paper, we address two key interrelated issues:

1. The classification of NBSs according to their definition (European Commission, 2015) and the consideration of their applicable values in multifunctional assets to achieve environments that enable quality living,
2. The provision of an adequate association with the terminology immanent to urban planning.

The review of practical cases claiming to apply NBSs (either as a concept or an actual solution) in urban planning reveals a variety of NBS classifications and interpretations that create confusion and shortcomings in understanding the relationship between NBSs and planning. The literature review, which was mostly limited to the European context, uncovered a classification based on various key aspects and spatial planning levels. Generally, NBSs are classified according to the societal challenges associated with adapting to climate change. Further, they are often classified according to the solutions’ co-effectiveness from an environmental, economic and social perspective when addressing said challenges. However, they are seldom classified based on the required (physical) conditions for their implementation or each NBS’s potential feasibility. In sum, there are two common ways in which they are classified: (a) the first involves using elaborate matrices that present environmental challenges and solutions, which are predominantly obtained as research projects’ outputs (e.g. Klimatek, 2016; Nature4cities, 2020; Naturvation, 2020), (b) while the second uses the various levels and types of ecosystem interventions and circularity challenges (e.g. Castellar et al., 2021; Eggermont et al., 2015; Langergraber et al., 2021).

The first way illustrates both the societal challenges associated with adapting to climate change and their multifaceted solutions in terms of the environmental, societal and economic benefits in relation to some of the basic units of (urban) space (e.g. buildings, open public spaces and bodies of water). The inclusion of a particular type of space or building in such a matrix addresses the fields of urban planning but in a highly fragmented way. In such representations, NBSs are usually addressed at a considerably fine-scale of architecture and landscape design because technical details are emphasised. Such emphasis excludes NBSs from relevant considerations at the small scale at the urban planning level, which is of utmost importance for guiding urban development in the relevant spatial or socio-economic context. Understanding this context is essential for identifying a city’s vitality.

The second classification approach defines NBSs as units or interventions for the level of engineering or management applied to ecosystems. Eggermont et al. (2015) suggested three types of interventions:

solutions involving no or minimal intervention in a space (e.g. protection of ecosystems); solutions involving extensive or intensive management and restoration of existing spaces with the aim of developing sustainable ecosystems and multifunctional spaces (e.g. parks and constructed wetlands); and solutions that create new ecosystems and spaces or interventions that use specific techniques to support natural processes. Such conceptualisations emphasise the value of using biotic components from nature and usually perceive NBSs as actions for creating green(er) cities.

The way they are classified clearly demonstrates that NBSs are not considered in the vocabulary of urban planning. However, urban planning is a tool that can ensure their implementation. The NBS concept lacks adequate associations with the vocabularies immanent to urban planning, such as land-use planning, morphology and built-structure patterns. Thus, there is a need to understand NBSs within the parameters of urban planning. In spatial planning, the issues associated with locating land-uses at sites based on their natural characteristics and their potential for NBSs – such that the NBSs can enhance the given characteristics of a particular site to the greatest possible extent – have not been sufficiently addressed.

1.3. Definitions and objectives of this paper

The term 'NBS' has been used in two different ways in this paper. The first usage refers to the concept of NBSs, while the second refers to the elements (individual objects) in the urban space that fit the NBS concept as defined by the European Commission (2015, 2022).

Biotic and abiotic components of nature are present in urban environments either as characteristics of the sites (such as wind flow) or as materials or resources. Both these types of components are crucial in helping to achieve the conditions required for quality living.

The natural processes that are the characteristics underlying the NBSs as solutions are the key focus when positioning the NBSs within the context of urban planning. Therefore, the aim of this study is to create a framework that can enhance our understanding of the NBS concept in the context of urban planning and, as a result, help develop the principles of NBS-driven urban planning, including programs and measures to support NBS-driven urban development.

The frame of understanding that better links NBSs and urban planning emphasises the 'solution' as the key driving force and builds upon the following reasonings:

- The practical potential of NBSs within the context of urban planning lies in a comprehensive understanding of NBSs that frames nature as a medium of dynamic processes involving both biotic and abiotic components.
- The classification of NBSs for the purpose of urban planning shall simultaneously address the role of natural processes in NBSs and the ability of natural processes to deliver results that address societal challenges in cities and urban environments; it sets up the following assumption:

NBSs have the potential to be accepted as a means of urban planning that is operative as a complementary set of solutions that addresses as many urban challenges as possible and achieves as many desired effects as possible.

2. Methodology

This paper follows a mixed-method approach that is based on a combination of a literature review, focus group research and expert evaluation. The methodology is closely linked to the frame of reasoning of the paper that directly reflects on the assumption stated in the Introduction section. To establish the frame of understanding to better link NBSs and urban planning, the following research flow was undertaken: (1) verification of NBSs' understanding and identification of the needs related to NBS-driven urban planning through a focus group to shape the research problem; (2) juxtaposing of the NBSs and societal challenges within a matrix, which includes the sub-groupings of both the juxtaposed components, and filling in the matrix; (3) enlargement of the matrix with identified urban patterns considering experts' knowledge; (4) verification of the final matrix with the focus group.

2.1. Verification of NBSs' understanding and identification of the needs related to NBS-driven urban planning through a focus group

The focus group consisted of five representatives: policymakers at the national level and experts in urban development and planning (architect, landscape architects and geographers) from the Ministry of the Environment and Spatial Planning of the Republic of Slovenia. The online discussions aimed to recognise current knowledge and understandings of NBSs among policymakers to be able to further set up possible linkages between (the interpretation of) NBSs and urban planning. The focus group discussions took place from September to November 2020.

2.2. Juxtaposing of the NBSs and societal challenges within a matrix based on a literature review

An exhaustive literature review was conducted on NBS-related papers published between January 2015 and April 2021. We focused on the general explanations of the NBS concept in the papers and the concrete solutions reported in the compendiums (catalogues) of individual NBSs. The search for relevant articles was implemented through the Web of Science and Google Scholar databases using the term 'nature-based solution(s)' for the topic, title and keywords of the articles. Initially, Web of Science yielded 266 articles, 166 of which were open-access. After reviewing the titles of each, 56 open-access articles were selected for further examination, and the following set of criteria was applied for these. First, the topic of the article needed to address the concept of NBSs and not deal with a specific NBS; second, the results of the article had to be relevant to the urban environment and address urban challenges; third, the research needed to have been conducted in the European context. Papers discussing solutions that are not suitable for implementation in European urban environments, e.g. solutions for agriculture and forestry or solutions for other continents, were eliminated. Ultimately, 22 papers were considered for further analysis. Next, we applied the same search strategy for Google Scholar and obtained 15 articles. Our results include restricted-access articles found in the Web of Science database. In total, we carried out in-depth reviews for 37 scientific papers. We also reviewed policy documents, manuals and reports on the topic of NBSs published by the European Commission, the European Environment Agency, the IUCN, and the World Bank. There were 17 such documents in total.

The following protocol was used for the literature review process: after identifying the main research challenges, we studied the extant literature and practices, screened them for inclusion, extracted and analysed the relevant information and, finally, aggregated the revised information into new forms of knowledge, which were structured into a two-dimensional matrix as shown in Figs. 1 and 3. The structure of this matrix corresponds with the two topics that seemed relevant for this literature review process: (a) the role of natural processes in NBSs and (b) the ability of natural processes to deliver results that directly correspond with the societal challenges in cities or urban areas.

With regard to the role of natural processes, we directly referred to the definition of NBSs established by the European Commission (2015). The NBSs were classified into three groups: (1) those that only use natural processes, i.e. reflecting the 'inspired by nature' part of the definition; (2) those that use and mimic natural processes, i.e. reflecting the 'supported by nature' part of the definition; and (3) those that only mimic natural processes, i.e. reflecting the 'copied from nature' part of the definition (see steps in Fig. 1). This review highlights the differences

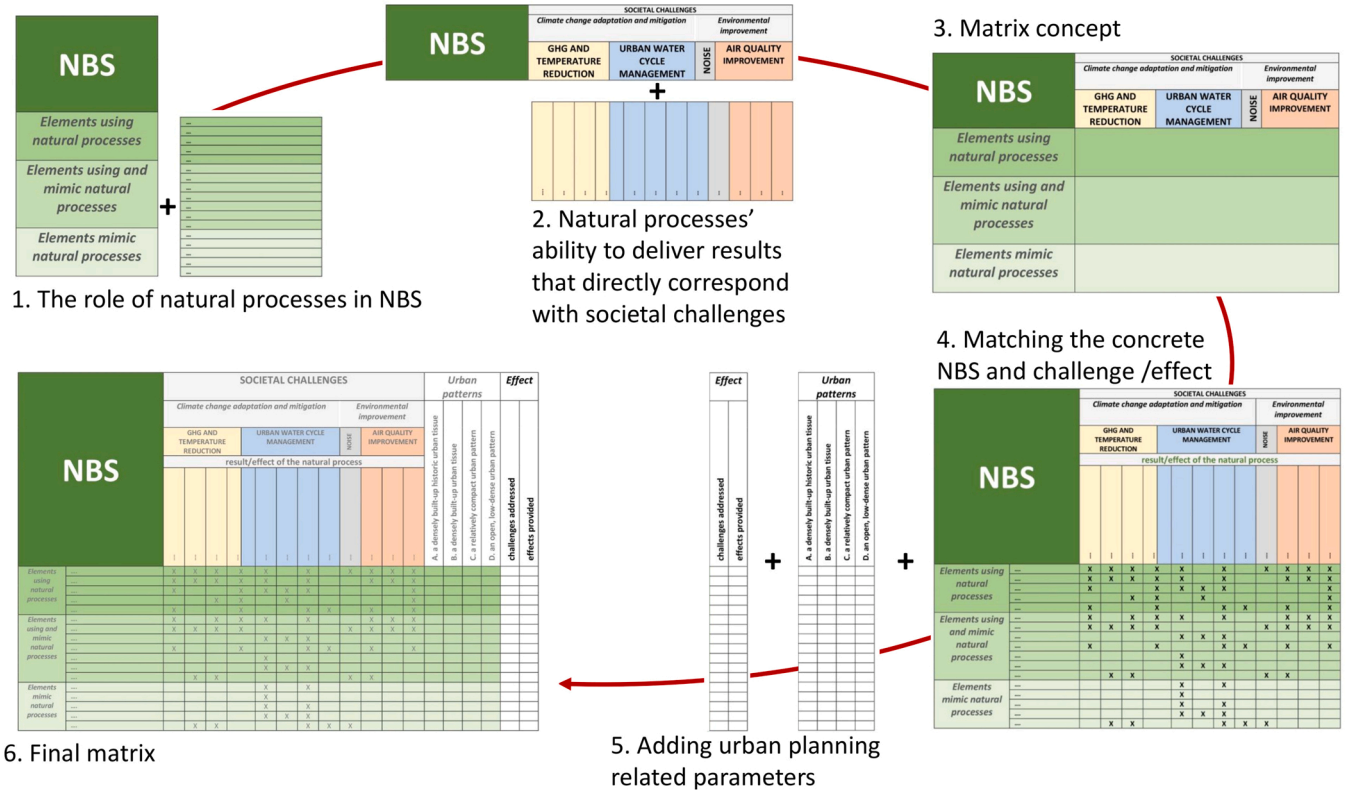


Fig. 1. Research workflow,.

among the in-depth examinations of individual NBSs as well as those among the demonstrations of solutions' technical characteristics in terms of their design, implementation or management (monitoring). Therefore, to classify the presented NBSs under the groups proposed above (see Fig. 3), we applied certain generalisations. For example, urban gardens are classified as natural terrain with low vegetation; urban forests are classified as natural terrain with high vegetation; intensive, extensive and constructed wet roofs are all generalised as green roofs.

As for the natural processes' ability to deliver results that directly correspond with the societal challenges in cities or urban areas, we closely examined the three most up-to-date NBS compendiums (Nature4Cities, 2018; Petsinaris et al., 2020; UnaLab, 2019) that resulted from the Horizon 2020 projects. We excluded NBSs that were classified as strategies and action plans, as they relate to the strategic planning and do not fit the criterion of the natural processes having the ability to improve the urban environment. These processes or their effects are carbon sinks, shadowing/cooling, heat-emission reduction, evapotranspiration, runoff reduction, water retention, water purification, noise attenuation, particle deposition, pollutant filtration and oxygen production. Further, we grouped the urban challenges defined in the literature (e.g. Castellar et al., 2021; Croeser et al., 2021) according to the following categories: (a) greenhouse gases and temperature reduction, (b) urban water-cycle management, (c) noise reduction and (d) air quality improvement. The right side of the matrix (Fig. 1) presents the list of processes or their effects and the corresponding challenges that they address.

The created matrix represents the basic framework. The rows of this matchmaking matrix indicate the representative concrete NBSs within the three main NBS groups defined by the involvement of natural processes. The columns present the results of the listed NBSs, which must be achieved to effectively address climate change adaptation and mitigation (via greenhouse-gas and temperature reduction and urban water-cycle management) as well as environmental improvement (via air quality improvement and reduction of noise issues). However, the matrix's final purpose is to illustrate which solution best solves each problem or set of problems in urban environments. Therefore, following the aforementioned NBS compendiums, the 'x' marks were placed in the matrix's matching cells to denote which type of NBS may best address the indicated challenge via which effect or natural process.

2.3. Enlargement of the matrix with identified urban patterns

To enhance the matrix's applicable value for urban planning, we enlarged it through a simple classification of urban patterns. The proposed urban patterns are highly descriptive in nature. They comprise descriptions from which an area's basic spatial structure, character and rough ownership structure can be deduced. These descriptions go beyond just the morphological aspects, and it makes sense to consider a broader contextual description because NBSs address social, environmental and economic dimensions. We defined the described spatial patterns as shown in Fig. 2.

The analysis of the NBSs listed in the matrix in relation to these four groups of urban patterns was based on expert evaluation. Three researchers from the field of spatial planning from the same research institution, who were knowledgeable about NBSs and urban/landscape planning, were involved in this process. The experts were asked to indicate whether an individual NBS can be assigned to a particular urban pattern according to the limitations and characteristics of the space (size, shape, cultural heritage restrictions, land use structure and ownership structure) and the characteristics of the NBS itself. Each expert first conducted an evaluation individually. Then, in the second round, they consolidated all values through a group discussion. After obtaining the filled-in matrix that followed the consolidated values, a simple scoring scale was established. Each NBS was assessed based on two parameters: number of societal challenges addressed and number of natural processes or effects enabled. There were four challenges in total. If an NBS addressed three or four societal challenges in the given urban

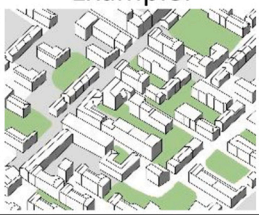
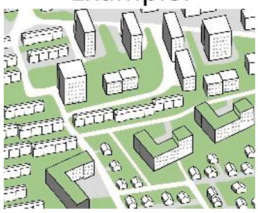
Type A	Type B	Type C	Type D
densely built-up historic urban tissue	***densely built-up urban tissue***	***relatively compact urban pattern with areas of low-dense and dense urban pattern***	***open, low-dense urban pattern***
Example: a historic town centre with multi-storey buildings in public and private ownership	Example: newly development with multi-storey buildings in public and private ownership	Example: an area of individual housing and multi-storey buildings in public and private ownership	Example: area of individual housing
Example: 	Example: 	Example: 	Example: 

Fig. 2. Urban patterns.

pattern, it was marked as good (G); if it addressed two challenges, it was marked as moderate (M); finally, if it addressed only one challenge, it was marked as weak (W). There were twelve natural processes or effects that were listed and associated with the four challenges. If an NBS enabled nine to twelve effects or processes to achieve improvement in the given urban pattern, it was marked as good (G); if it enabled five to eight of them, it was marked as moderate (M); and if it enabled four or less of them, it was marked as weak (W). The scoring system (good, moderate and weak) illustrates the suitability and relevance of each NBS for the studied urban patterns (see Fig. 3).

2.4. Matrix verification through a focus group

The proposed matrix includes three layers of information that is crucial to know about NBS inclusion in urban planning. These are the three core groups of NBSs, each including concrete NBSs; a spectrum of societal challenges with the corresponding list of natural processes or effects enabled by them to address potential improvements in urban environments in relation to the challenge stated; and the consideration of a spatial dimension with regard to the inclusion of the listed NBSs, which is represented by four urban patterns. The filled-in matrix (Fig. 3) enables interpretation based on these layers of information. A verification of this matrix as a source of information and as a means of interpretation for the purpose of urban planning was conducted using a focus group. An online meeting with the same five representatives – the national-level policymakers who participated in the focus group in the first step of this research – was held in April 2021. An open discussion was carried out on the three layers of information, and their valuation was discussed and confirmed as being suitable as a base for NBS-driven urban planning.

3. Results

The focus group discussion on the knowledge and understanding of NBSs showed that while the term itself is quite clear, the implementation and understanding of NBSs in the context of urban planning – based on existing planning procedures and documents – can be confusing and need further discussion. However, the focus group discussion showed that the initial associations of NBS were often linked with urban green- and greening-related components, which are further linked with benefits pertaining to health and biodiversity, as reflected in the literature as well (e.g. Seddon et al., 2019). When addressing the NBS-related spatial/urban planning perspective, the focus group discussion resulted in strong support for the recognition of the abiotic components of nature as the conditions and potential abilities of locations that can be recognised as a baseline for urban development. This reflects McHarg's (1969) conceptions and shows a strong preference towards the recognition and inclusion of natural processes when considering urban planning and development, especially to provide or improve environmental and social benefits. NBSs as a solution-driven concept that can influence urban design implementation projects was recognised as a very promising option of urban planning. Therefore, the construction of the matrix followed a gradual approach, from the juxtaposing of the NBS and societal challenges within a matrix, which included the sub-groupings of both the juxtaposed components, to upgrading the matrix with spatial components that refer to four typical urban patterns and with columns that address the suitability of each NBS, as shown in the Methodology section (Fig. 1).

3.1. Establishing a better linkage between NBSs and urban planning and design

Our analysis focuses on the interpretation of the matrix's cells based on the characteristics of the NBSs available in the literature and the indication of each individual NBS as a means or measure for using or enabling the elaborated natural processes or effects to address the recognised challenges in urban environments, as shown in Section 2.2. The analysis demonstrates (see Fig. 3) that the solutions that address the challenges related to air quality and temperature are mainly available within the NBSs that use natural components and processes. Further, NBSs that address the urban-water-cycle-related challenges are much more evenly spread across the matrix. They span from solutions that

NBS		SOCIETAL CHALLENGES												Urban patterns				Effect. of specific NBS	
		Climate change adaptation and mitigation								Environmental improvement									
		GHG AND TEMPERATURE REDUCTION				URBAN WATER CYCLE MANAGEMENT				NOISE	AIR QUALITY IMPROVEMENT								
		result/effect of the natural process																	
		carbon sink	shadowing / cooling	less heat emitted	evapotranspiration	surface runoff reduction	peak runoff reduction	water retention	water cleaning	noise containment	particles deposition	filtration of pollutants	oxygen production	A. a densely built-up historic urban tissue	B. a densely built-up urban tissue	C. a relatively compact urban pattern	D. an open, low-dense urban pattern	challenges addressed	effects provided
Elements using natural processes	natural terrain with high vegetation	X	X	X	X	X		X		X	X	X	X		X	X	x	G	G
	natural terrain with low vegetation	X	X	X	X	X		X			X	X	X		X	X	x	G	G
	retention pond	X			X	X	X	X					X			X		G	M
	pond			X	X		X						X			X		G	W
	swale	X			X			X	X		X		X		X	X	X	G	M
Elements using and mimic natural processes	green roofs *	X		X	X	X		X			X	X	X		X	X	X	G	M
	vertical green*	X	X	X	X					X	X	X	X	X	X	X	X	G	M
	detention pond					X	X	X								X	X	W	W
	constructed wetland	X			X			X	X		X		X			X	x	G	M
	planting pit system					X									X	X	x	W	W
	underground water storage **					X	X	X						X	X	X	x	W	W
	physical structure of the built environment		X	X						X	X			X	X	X	x	G	W
Elements mimic natural processes	rainwater harvesting**					X		X						X	X	X	X	W	W
	pervious pavement					X								X	X	X	x	W	W
	sinkholes					X		X						X	X	X	X	W	W
	underground water storage **					X	X	X						X	X	X	X	W	W
	selection of natural materials/ sources		X	X				X	X	X				X	X	X	x	G	W

Fig. 3. The match-making matrix, which includes urban patterns and the effectiveness of the specific NBSs in terms of the number of effects of the natural processes enabled, and the number of societal challenges addressed using the scores of G = good, M = moderate, W = weak, as defined in the Methodology section.

directly use natural processes to hybrid solutions and those that only mimic nature. The analysis also indicates that NBS for natural/rough terrains with substantial vegetation are the most versatile in terms of alleviating or improving the widest range of problems. However, it should be noted that existing cities and urban areas often lack sufficient space to accommodate large, highly vegetated green spaces. Further, the mature phase of such greenery-based NBSs would not be reached quickly enough to mitigate the negative effects in the urban environment. In such situations, therefore, it makes sense to orient the development of NBSs in a way that, for every challenge, there is a solution either among NBSs that mimic nature or among hybrid NBSs (i.e. those that combine both natural processes and the mimicry of natural processes). Thus, further analysis was conducted on the applicable possibilities and suitability of the studied NBSs in the four different types of urban environments (see Fig. 3).

Fig. 3 shows that the NBSs that directly use natural processes (e.g. natural terrain with substantial vegetation, which is often associated with parks in urban areas), especially in dense urban patterns, are generally more difficult to implement because of space constraints. Hence, the approach that may be more appropriate in such situations may be based in a set of solutions that mimic nature. Accordingly, it is important to note that nature comprises both biotic and abiotic components. For example, the solutions for reducing the occurrence of heat islands in cities lie in the selection of suitable building materials and their appropriate treatment as well as knowledge of the physical characteristics of the components of nature's abiotic elements, the orientation of buildings and their compositions; these factors can influence the natural ventilation of rooms (building scale) or areas (urban scale).

Our results indicate that the relatively compact urban pattern (Pattern C) can accommodate all 17 NBSs considered in this study. In contrast, for Urban Pattern A (densely built-up historic urban tissue), only eight of them can be implemented, and none of these use natural processes. The largest number of NBSs of any type and those that address the full range of challenges can be accommodated by areas of mixed spatial character. A significant proportion of European cities and towns can be identified as having a mixed spatial character (e.g. type C: a relatively compact urban pattern with areas of low density and dense urban patterns). In the case of open, low-density urban patterns (e.g. type D), we want to draw attention to the role that municipalities and local governments can play in the provision and/or introduction of NBSs (which is why the small 'x' mark was introduced). It indicates solutions that are appropriate under certain conditions and for which local planning documents would need to be accepted first. Such urban patterns usually affect single-family homes, and the associated local planning documents could play a significant role in implementing NBSs for households' water management. Planning the public communal

infrastructure can become highly NBS-oriented instead of maintaining the so-called grey infrastructure planning concept.

Further, the analysis focused on how many challenges and how many actual effects of the natural processes each studied NBS may enable. Through this, the aspects of multifunctionality and the multi-layered benefits of the solutions were addressed. This analysis indicated that natural terrain with high vegetation enables or uses the most natural processes, addresses all four societal challenges and can be implemented in three of four types of urban patterns (all except Type A). Natural terrain with low vegetation also represents a considerably multi-effective NBS for urban environments that are located outside densely built-up historic urban areas. It is slightly less multi-effective when there is, among others, also a need for noise reduction. In contrast, NBSs that mimic natural processes are mainly scored lower in terms of the effects they enable as well as the challenges they can address, as there are fewer of them and they are usually quite narrowly focused on their impacts or functions. However, interestingly, the physical structure of the built environment may follow the natural morphology of the location and consider the natural abilities and qualities so as to build upon them such that the material and energy flows are not disturbed. This maintains the characteristics of the original site and, therefore, can effectively enable some of the effects that are already immanent to the site, for example, through the appropriate orientation, height and width of buildings, spacing between them as well as appropriate material selection and treatment. This is particularly crucial where, because of the lack of available space, there is no room to introduce solutions that directly use natural elements.

3.2. Connecting individual solutions for a cumulative effect

Further, the matrix (Fig. 3) shows that some solutions adequately address several problems or constraints in urban environments at the same time. It suggests that NBSs can be understood as a complementary set of solutions for improving the quality of life in cities rather than as a set of individual solutions pursued in isolation. One NBS cannot enable all the natural processes needed in an area; however, the matrix illustrates the possibilities of how different NBSs can be implemented together in appropriate combinations in specific spatial units to successfully address the identified challenges. Thus, an NBS as a set of many interconnected and interdependent individual NBSs with specific purposes and characteristics, which comprehensively addresses one or more societal challenges (e.g. a network of several green roofs, retention ponds and other NBS elements aimed to significantly reduce heat islands, improve air quality, etc.), may work as an overall solution and have a cumulative effect on various societal challenges. In this way, we can set up a system that works as an NBS, which may have a stronger impact through the effect of the scale and variety of connected NBSs.

4. Discusion

When considering NBSs as a system, it is important that solutions are not implemented randomly. It is important to have a good understanding of the interaction effects of different NBSs or the multiplicity of effects of individual NBSs for establishing systemic solutions. In urban planning, it is also crucial to define the impact's spatial extent, i.e. (a) the solution's impact area and (b) the impact area of the availability of the resources required for the solution. While there are some examples of NBS evaluations for different challenges (e.g. Ercolani et al., 2018; Kuller et al., 2019), the studies were mainly local and project-based. Although they represent an important branch of the development of NBSs, and their role in urban planning seems highly influential, these topics have not yet been adequately explored. Importantly, NBSs can offer a comprehensive concept and the actual implementation of solutions by providing the necessary information and mechanisms to identify sites' natural resources and the potential benefits of NBSs at all levels of urban development (building, neighbourhood and city). Therefore, the currently scattered knowledge must be brought together and, through intensive interdisciplinary work, enriched and clearly focused.

4.1. New knowledge about NBSs for urban planning

Although NBSs offer a starting point for integrating the understanding of natural processes into the instruments of urban planning and design, this field remains under-researched (e.g. Bush and Doyon, 2019; Smid and Costa, 2017). A review of the current literature and practices in Europe also shows that NBSs cannot yet be sufficiently holistically considered in either urban-development policy or more practical spatial planning perspectives. The matrix presented in Fig. 3 illustrates how different types of NBSs can be implemented in the defined urban patterns that correspond to medium-sized and large European cities. The presented frame of understanding in the form of a multifaceted matrix is a source for interpretations that presents the linkages between the dynamic processes of nature via their environmental aspects and planning possibilities. It can encourage decision-makers (especially at the local level) to implement NBSs, especially because the matrix shows that a single NBS can address multiple problems and contribute to improvements in multiple areas (challenges) and different urban environments, that there can be several different solutions to the same problem and that, therefore, we have a choice of NBSs for different environments. Our findings suggest that a classification of NBSs shall reflect both the solution's type (i.e. the extent to which it uses or mimics a natural process) and the context in which it is implemented. Thus, NBSs that mimic natural processes may be support the achievement of a good quality of life in already intensively built-up areas. However, in areas where space constraints are not considered limitations, priority should be given to the solutions based on natural processes for all new investments and urban regeneration actions, while the other solutions (mimicking or hybrid) can be considered supplementary. Further, it is also crucial to recognise the conditions that the site needs to meet for implementing these NBSs, the (natural/natural-like) resources that are needed for the functioning of the NBSs and how the resources can be provided. This implicates that NBSs tend to be self-sustained (as much as possible).

4.2. Integrating NBSs into spatial planning systems

In addition to the initial understanding that NBSs could contribute to connectivity among sectors, for them to have a significant breakthrough in the context of urban planning also requires the development of an appropriate interpretation of NBSs within the planning categories at the strategic and implementation levels. Thus, it is particularly important to promote the integration of NBSs into existing spatial planning systems at the implementation level.

Here, the challenge is associated with how to upgrade such documents with the representation of NBS-related information and characteristics, in both the text-based and graphical components, to align with the existing urban planning language rather than being a separate appendix that merely provides examples that might not be fully considered for the area or location of interest. It should be noted that, graphically, NBSs cannot be represented as land-use categories. As they are solutions with areal impacts, it would be helpful to show some of their characteristics graphically as well, especially at the master plan stage. In contrast, the urban design stage can benefit from more technical representations of NBSs. There are known examples in urban planning in which master plans show layers of information that address concrete entities of urban development that go beyond landuse presentation. For example, the Municipality Master Plan for Ljubljana (Municipality of Ljubljana, 2001, 2018) introduced a green system as a part of the master plan information. Nowadays, such a system would perfectly fit the concept of green infrastructure (European Union, 2013). This master plan introduced a category called the green-system regime, which has a transparent layer that covers the appropriate areas marked for various

land uses, ranging from green and residential areas to forests and agricultural areas, as well as land used for transportation. Such layers communicate the necessity for managing places with different land uses in a way that ensures the continuity of green infrastructure. A discussion with the experts and focus group representatives confirmed that the representation of a cumulative NBS (i.e. a complementary set of NBSs) could be inspired by such approaches in urban planning. (Fig. 4).

Our results also revealed that there are several aspects that can be considered to directly link urban planning and NBSs. Further research should focus on criteria development for (a) identifying areas that are suitable for implementing NBSs, (b) urgency for choosing NBSs as a solution, (c) NBS impacts and their evaluation and (d) setting up and achieving multi-functionality/multi-use of space, which may create a foundation for setting technical standards for NBSs implementation or intervention. This is seen as a contribution of this paper that may help bridge the gaps between urban planning and NBS implementations and can serve as the basis for the development of guidelines, regulations, policies or recommendations to support urban planning using NBSs.

4.3. Limitations

This paper discusses a new approach to building and promoting a frame of understanding that would better link NBSs and urban planning. In contrast to the other related concepts applied in the last decades, such as ecosystem services, the framework developed here not only includes the understandings of ecosystem services but also goes beyond it. This is similar to the work of White et al. (2021), who argue that the ecosystem services (delivered by natural capital) are not the only source of benefit that can contribute to solutions that are nature-based, emphasising that there are also technological services and labour enabled by human capital. We stress the role of solution as the key means in linkages of NBS and urban planning. Thus, in NBSs where the outcome is recognised as the result of the specific natural process that an NBS is based on, instead of the benefits, the effect of the solution is addressed or measured. However, there are two sets of limitations that need to be addressed: the first addresses the limitations of the study and the second addresses the limitations of the proposed framework.

First, the foundation of the research is built upon the associated scientific literature and covers the latest available knowledge. However, the practical experiences considered in the focus group are limited to the representatives – the policymakers of one state – and, therefore, one spatial legislation frame, which includes the initial understanding of NBSs and their potential for inclusion in spatial planning. The performance of a comparative study in other European countries would diminish these limitations and strengthen the background for the framework's foundation. This can be realised by working towards the creation of international policy labs and/or the acquisition of international projects that address the issues of NBS identification and the possibilities for their integration into spatial planning within the existing legislative frameworks.

Second, some limitations stem from the fact that the creation of this framework is a necessary first step to bring NBSs and planning closer together, but it is not sufficient. The framework is, to a certain extent, simplistic and built upon the known and most commonly addressed NBSs and four simplified types of urban patterns. The framework is less likely to be directly used by urban planners to find a suitable solution for their urban challenges in their specific urban pattern. However, it may more likely be used to obtain a broader understanding of NBSs for urban planning and critically translate the same in practice to the specific local urban environments under consideration. Certain solutions that appear to be appropriate in one environment may be inappropriate elsewhere due to the existence of different (micro) local parameters (climate, geological base, native vegetation, etc.) and social environments. The presented matrix makes it possible to determine solutions through urban planning for such local social challenges in specific urban patterns within the presented NBS elements in this matrix based on the natural processes that are a crucial characteristic of a particular NBS.

In this respect, the limitation of this study is that certain information, such as the impact area of the solution it envisages for the effective integration of various NBSs into cumulative solution sets, is not yet known, and more concrete conclusions are not possible. However, the contribution of this work is the systematic approach that results from the proposed framework that can be further developed using carefully selected criteria by considering economic, ecological and social aspects

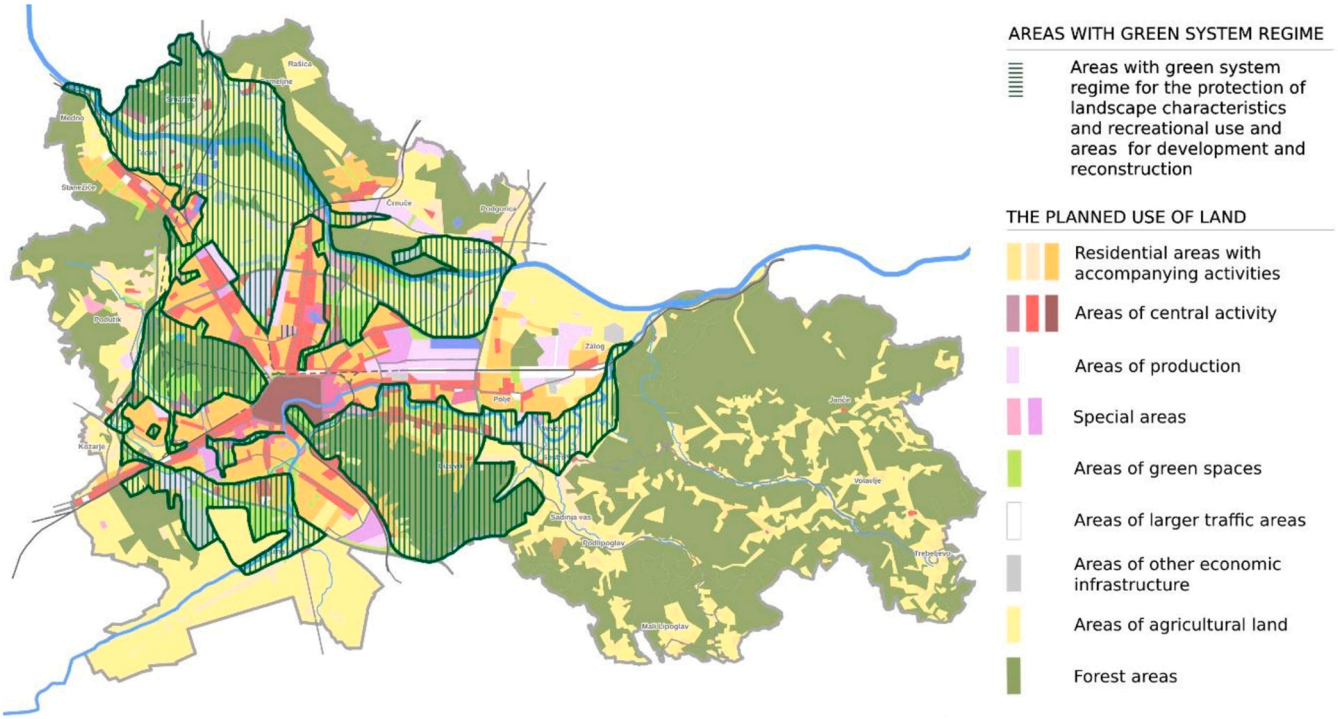


Fig. 4. Municipality Master Plan for Ljubljana, which introduced the green-system regime (Municipality of Ljubljana, 2018).

to achieve added value in NBS-related urban planning.

5. Conclusion

NBSs are solutions based on the principles of nature and are characterised by their multi-faceted ways of addressing the problems of contemporary society in the context of accelerating spatial development. Since the relevant knowledge on NBSs remains scattered, we analysed state-of-the-art NBS concepts and concrete solutions in urban settings and created a framework of understanding that is oriented towards urban planning needs. Our results showed that understanding the interaction effects of different NBSs or the multiplicity of the effects of a particular NBS is important for establishing a complementary set of solutions (as opposed to individual solutions pursued in isolation) aimed at improving the quality of life in cities and other urban environments. As for different urban patterns, it is particularly important to identify the spatial scales of impacts – from the impact area of the solution to that of the resources required for the solution's operation.

Based on the evaluation of a single NBS within a specific urban pattern, the understanding of NBSs should be promoted in the context of urban planning parameters, e.g. morphology and structure, as there is no universal solution for all challenges and urban patterns. The urban environment involves space constraints, making it even more important to look for a wider range of solutions that follow the NBS concept and are based on the abiotic components of nature. It is precisely on the issue of ensuring the rational use of space that NBSs can provide the interface between sectoral policies and actions to establish the path towards climate neutrality, resilience and adaptive use of space and, thus, towards a good quality of life and rational spatial development in cities and other urban areas. It is particularly important to promote the integration of NBSs into existing urban planning systems at the implementation level. This integration will enable communication among the sectors at a familiar level, such as energy and sectors addressing other primary resources (e.g. forestry and agriculture), and strengthen the convergence of sectoral perceptions regarding the opportunities and possibilities for sustainable urban development through NBSs. Based on this framework of understanding, future research is needed to identify the most appropriate spatial documents in which NBSs should be included and how they should be presented graphically.

For the successful integration of NBSs into urban development, this paper recognises the following recommendations, which are presented by priority: development of criteria for the recognition and implementation of integrated NBSs in urban planning; development of guidelines and recommendations for such NBS-integrated urban planning; raising of the visibility of NBSs and their effects on quality of life by providing education on NBS-integrated urban planning and promoting transdisciplinary research on urban planning with the aim of ensuring the effectiveness of NBSs in local contexts; facilitation of the transfer of knowledge from transdisciplinary research into urban planning practice, including full integration into regional and municipal planning documents, such as urban design documents; and supplementation of existing regulations with commitments to evaluate the economic impacts of the envisaged NBSs and the economic viability of their implementation. Thus, with the framework of understanding established to better link NBSs and urban planning, we have contributed to the recognition of the complexity of the NBS concept and its potential for NBS-driven urban planning and decision- and policy-making.

CRediT authorship contribution statement

Barbara Goličnik Marušić: Conceptualization, Writing – original draft preparation, Investigation, Visualization, Data curation, Methodology, Writing – review & editing, Supervision. **Manca Dremel:** Conceptualization, Writing – original draft preparation, Investigation, Visualization, Data curation, Methodology, Writing – review & editing. **Živa Ravnikar:** Conceptualization, Writing – original draft preparation, Investigation, Visualization, Data curation, Methodology, Writing – review & editing.

Declaration of Competing Interest

We, the authors, Barbara Goličnik Marušić, Manca Dremel and Živa Ravnikar, confirm that we have written entirely original work and that the work and words of others has been appropriately cited or quoted. We fully complied with ethical behaviour regarding authorship and originality, including acknowledgement of sources, and have avoided any form of plagiarism. We have not published or submitted any other paper describing the same issues and/or results derived from the selected research. We have worked together on the paper and are all very familiar with the original research on which the paper is based on. We have all seen the last version of the paper and agreed to its submission for this particular publication. Issues on hazards and human or animal subjects are not relevant to this paper, We also assure the editors that there are no financial or any other substantive conflicts of interest that might be construed to influence the results or interpretation of the manuscript we have submitted.

Data Availability

Data will be made available on request.

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