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Nature-based solutions and policy instruments towards an optimal urban design

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Abstract Urban planning is crucial to promote resilience and liveability of cities in the face of current urbanization patterns and climate change challenges. Nature-based solutions (NBS) are viable alternatives to grey infrastructure, with multiple environmental, social and economic benefits and co-benefits, comprehensively contributing to the sustainable development goals. Despite their widely recognized importance, socio-economic dynamics are less studied – namely in simulation approaches. Additionally, they are rarely considered alongside policy instruments to either steer or potentiate the NBS socio-economic and urbanization impacts. Hence, the objective of this paper is to assess the effectiveness of several simulated NBS and policy instruments in different case studies with different socio-economic contexts. It aims to provide municipalities and policy-makers evidence to learn from and extrapolate expected outcomes based on urban characteristics. From a participatory approach perspective, the methodology included NBS co-design workshops with municipalities as well as NBS and policy instrument scenario simulations. Regarding NBS impacts, attractiveness has proven to be the most relevant characteristic, in combination with urban pre-greenness, size and/or location. Furthermore, NBS in combination with policy instruments demonstrated the potential to maximize NBS benefits and control urbanization processes, such as gentrification and urban expansion, namely though real-estate taxes, subsidies and zoning.

Keywords: Nature-Based Solutions, Policy Instruments, Simulation modelling, Urban design

1. Introduction

Urban planning is crucial to promote resilience and liveability of cities in the face of current urbanization patterns, economic development and climate change challenges. Bearing this in mind, the United Nations Sustainable Development Goals (SDGs), namely SGD 11, highlight the importance of promoting safe, inclusive, sustainable and resilient cities and human conditions (Bockarjova et al., 2020; Dell'Anna et al., 2022; Viti et al., 2023).

Nature-based solutions (NBS) are actions supported and inspired by nature to protect and sustainably manage ecosystems (Mendonça et al., 2021). NBS are considered effective tools to address urban challenges with growing attention from policy-makers, action plans and overall policy initiatives, namely in Europe (Cortinovis et al., 2022; Frantzeskaki, 2019). Through the operationalization of ecosystem services, the concept stresses a participatory approach and economic cost-effectiveness in the medium to long-term, in addition to the environmental benefits (Cortinovis et al., 2022; Dushkova & Haase, 2020).

In fact, NBS uphold several socioeconomic benefits, such as physical and mental health improvement, social cohesion, increased engagement, green jobs as well as associated recreational and aesthetic values that lead to increased property values and urban compactness Bockarjova et al., 2020). However, the impacts depend on the NBS characteristics and socio-ecological context of the area in which they are implemented (Martin et al., 2021). Indeed, negative impacts might also accrue from NBS implementation, such as urban expansion, habitat fragmentation and green gentrification (Cortinovis et al., 2022; Martin et al., 2021).

To address the design of NBS, control negative impacts and mainstream its implementation, policy framing to foster development strategies alongside citizen acceptance is mandatory (Cortinovis et al., 2022; Martin et al., 2021). Policy instruments can be divided into information, planning and economic – ranging from binding, incentivizing to guidance (Mendonça et al., 2021) and have the potential to foster NBS impacts and mitigate gentrification and expansion phenomena (Mendonça et al., 2020; Oliveira & Meyfroidt, 2021; Mendonça et al 2023c).

Some studies evaluate NBS scenarios impact on urban areas (Cortinovis et al., 2022), including design (Chen et al., 2022; Wei et al., 2022) and optimal location (Gwak et al., 2017). Others have assessed socio-economic impacts as green gentrification, property prices and urban form (Anguelovski et al., 2018; Dell'Anna et al., 2022) but mostly through statistical and review approaches and still focus, to a large extent, on biophysical impacts. In addition, despite the recognized importance, the connection of NBS and policy instruments is still mostly theoretical and focused on information instruments (Mendonça et al., 2021; Oliveira & Meyfroidt, 2021; van der Jagt et al., 2023).

Hence, there is limited knowledge regarding the optimal location and characteristics of different NBS and its impacts on urbanization patterns, including the socio-economic and land use benefits and dis-benefits as most studies consider single-case studies (Bockarjova et al., 2020; Dushkova & Haase, 2020; Frantzeskaki, 2019). From a holistic perspective, there is also a need to better integrate NBS in policy literature to attain implementation, acceptance and maximize potential benefits, namely using modelling approaches (Bockarjova et al., 2020; van der Jagt et al., 2023).

Accordingly, the objective of this study is to assess the effectiveness of several NBS and policy instruments across different socio-economics contexts and land use patterns from an urban design perspective. To this end, we compare several simulated NBS scenarios and policy instruments to either potentiate or mitigate NBS impacts.

2. Methodology

This study provides an overview of the socio-economic and land use impacts of simulated NBS and policy scenarios in Eindhoven (Netherlands), Tampere (Finland) and Genova (Italy)- Front runner cities for the UNaLab Project- and policy instruments in Aveiro (Portugal) and Genova (Italy).

To this end, firstly, co-design workshops were held with the Municipalities (Eindhoven, Tampere and Genova), in which the participants pinpointed a list of urban problems as well as NBS with potential to address them. The final list included a classification of the NBS in different attractiveness levels: type 1 (urban) high attractive, type 2 (neighbourhood) medium attractive and type 3 (local) low attractive.

In turn, the NBS scenarios were simulated for the different case studies, using SULD (Sustainable Urbanizing Landscape Development; Roebeling et al., 2007), a spatially-explicit hedonic pricing simulation model that was adapted to the study areas, to evaluate the NBS socio-economic and land use impacts. For the model simulation results, see Mendonça et al. (2023a, 2023b and the UNaLab online NBS systemic decision support and simulation and visualization tool (SDST/NBS-SVT; https://unalab.eng.it/nbssvt_v4/).

In addition, the same model was used to evaluate the impact of policy instruments, including planning and economic. These were simulated to potentiate or mitigate the impact of NBS and contribute to more sustainable urban patterns, as in relation to urban sprawl and green gentrification processes (Mendonça et al. (2020) and Mendonça et al. (2023c) for the simulations).

3. Results and discussion

Green roofs were simulated in Eindhoven, Tampere (2 scenarios) and Genova (see Figure 1 in Annexes for their location). Scenarios were simulated with different sizes, ranging from 7 to 42 ha, all with the lowest attractiveness level, type 3, due to their limited accessibility. The green roofs located both in peripheral and central areas and in areas where all households types (RES) inhabit depending on the case study (Table 1 in Annexes). Results show that, in cities with lower shares of green urban areas (Eindhoven and Genova; Figure 1), their impact was positive, with a contraction of the urban area, decreased housing quantity and increased housing price (Table 2 in Annexes). The impact was small for Genova and more significant in Eindhoven, as the green roof implementation area in Eindhoven was considerably larger. Nevertheless, for Tampere, an urban expansion was visible, as the low-income households (RES1) contract near implementation area, creating a decreased housing demand in intermediate and peripheral areas. This also created an overall increase in housing quantity and decrease in housing prices, contributing to the urban sprawl phenomenon. Within the green roofs scenarios (type 3), the urban pre-greenness was the most important characteristic, as the broad pre-existence of green areas implies reduced demand for new green interventions, namely low attractive ones, as demonstrated by some authors (Cortinovis et al., 2022; Wei et al., 2022). Additionally, the size of the green roofs also had impact, with results being more significant for Eindhoven than for the other case studies, as widely recognized (Dell'Anna et al., 2022; Wei et al., 2022). Overall, green roofs' location was not a key factor in their impact, as central interventions did not show additional benefits. Moreover, the RES type in the intervention area was not decisive, with the biggest impact the scenario around industrial areas, as the NBS is not attractive enough to spike demand from higher income households (RES3).

The street trees scenarios were simulated in Tampere and Genova (Figure 1). Both were considered low attractive (type 3), with 15 ha and 4 ha, respectively, in central areas and impacting RES1&2 (Table 1).Following the same trend as the green roof scenarios, in Tampere (high pre-greenness), the low attractive NBS created a small increase in the urban area and housing quantity, alongside a small decrease in housing prices (Table 2). In Genova, the impact was negligible, most likely due to the small size and attractiveness in line with Cortinovis et al. (2022) and Frantzeskaki (2019), pinpointing that if the NBS size is too small, the impact might be negligible, as interventions need to be appealing. Once again, the location did not show to be impactful, as both scenarios were central and even urban expansion took place. These results highlight, once again, that, for low attractive NBS, the urban pre-greenness is the most important characteristic, followed by the intervention size.

The urban park scenario was simulated, in Genova (Figure 1), considered medium attractive (type 2) NBS due to the recreational potential of an urban park yet with a small size (1.6 ha). The scenario is central and affects mostly medium-income households (RES2) – Table 1.

Despite the small size of the NBS, it created a small reduction in the urban area and housing quantity and increase on housing prices (Table 2). These results emphasize the importance of the attractiveness level, as the urban park had more significant results even being smaller than any of the considered low attractive (type 3) interventions. Additionally, its central location might have contributed to its contraction potential, as well as being built in a low pre-green areas (Cortinovis et al., 2022; Wei et al., 2022). However, this scenario was not attractive enough to attract RES3, maintaining the area household pattern. Overall, these findings are supported by Chen et al. (2022), that pinpointed that size is important but less than attractiveness. Notwithstanding, these results might be fostered with bigger interventions as the size is acknowledged to increase the urban parks social benefits (Dell'Anna et al., 2022).

The green and blue space scenario was simulated in Genova (Figure 1), considered a highly attractive (type 1) NBS, with 17 ha and intermediary location, where RES2&3 lived (Table 1). This scenario, combining the attractiveness level with the considerable size, led to the greatest reduction in urban area and housing quantity alongside the increase in housing prices (Table 2). These results reiterate the crucial role of the attractiveness level of the NBS implemented, usually associated with blue spaces (Bockarjova et al., 2020; Viti et al., 2023). Nevertheless, this scenario created some green gentrification (Mendonça et al., 2023b), where RES3 bought-out RES2 due to the added aesthetic value of the area, being able to afford more expensive housing (Bockarjova et al., 2020). This points-out the importance of location and, consequently, RES type in the intervention area in more attractive and bigger NBS (Viti et al., 2023; Wei et al., 2022), especially in low-green urban areas (Cortinovis et al., 2022).

Two river daylighting interventions were simulated (Tampere and Genova, Figure 1), both considered highly attractive (type 1) interventions, with 4 ha and 0.7 ha, respectively. The two NBS are peripheral and built in locations where RES3 resided (Table 1). Both resulted in contraction of the urban area, decrease of the housing quantity and increasing housing prices, with results being more significant in Tampere (Table 2). Hence, these findings confirm that size of highly attractive NBS is more important than urban pre-greenness (Chen et al., 2022; Wei et al., 2022). Moreover, they accentuate that the location of highly attractive NBS is important, as no gentrification was observed given that RES3 already lived in the area (Wei et al., 2022).

To potentiate or mitigate impacts of NBS scenarios, such as urban sprawl and green gentrification, additional policy instruments simulations were carried-out in Aveiro and Genova (Table 3 in Annexes; see Mendonça et al., 2020, 2023c). Regarding the urban sprawl containment potential, the flat property tax and public transport subsidy for RES1&2 showed the more significant results, with decrease in urban area, housing quantity and increased housing prices. The linear property tax for RES3 from type 1 environmental amenities as well as zoning instruments also had a positive impact on the urban compactness, while a land tax had no impact (land costs are too low for impact) and the property subsidy to RES1&2 even caused a small urban expansion. Overall, economic instruments showed to be effective in steering sprawl (Oliveira & Meyfroidt, 2021).

With respect to the green gentrification phenomenon that took place in the green and blue scenario in Genova, the linear property tax to RES3 from type 1 environmental amenities and zoning instruments were the most effective in discouraging the buy-out phenomenon, while still having positive impacts on urban contraction (Oliveira & Meyfroidt, 2021). The property tax subsidy to RES1&2 controlled the green gentrification, even if not completely, but created some additional urban sprawl. Comprehensively, a policy mix might be able to combine the potential of economic, planning and information instruments in curbing gentrification processes and potentiate overall NBS uptake (Dushkova & Haase, 2020; van der Jagt et al., 2023).

4. Conclusions and policy recommendations

This study assesses the effectiveness of several NBS and policy instruments, to either potentiate or mitigate NBS impacts, across different socio-economic contexts and land use patterns from an urban design perspective. To effectively design NBS, socio-economic impacts must be considered and inequalities addressed in addition to their biophysical benefits (Anguelovski et al., 2018). Moreover, policy-wise, the implementation success requires knowledge about different NBS types and expected benefits at the landscape scale, as they depend on urban characteristics and households preferences (Bockarjova et al., 2020; Viti et al., 2023).

Results highlighted the importance of NBS attractiveness level, in combination with urban pre-greenness, size, and/or location of the intervention. In fact, for low attractive NBS, the urban pre-greenness was the second most important characteristic, as in urban areas with high pre-greenness the demand for additional NBS might be limited and can even lead to some urban expansion. The size also has an impact on low attractive NBS, as its impact might be negligible if they are too small. Location and household type did not influence the low attractive interventions' impact. Conversely, in high attractive NBS, the size was the most important factor, with more significant impacts for bigger interventions. Urban pre-greenness was not as impactful, as for high attractive NBS demand still exists even in greener urban contexts. In this case, location and household type were also important, with more contraction associated with less peripheral interventions and the possibility of generating green gentrification processes if NBS are built in lower income locations.

Hence, more attention should be paid when designing and planning a high attractive NBS as it will have greater impact on the urban dynamics. For urban sprawl containment, big and low attractive or more central and high attractive resulted in the biggest urban compactness. In addition, big and high attractive solutions implemented where lower income households reside areas might led to green gentrification, which can be addressed through policy. Comprehensively, policy instruments can mitigate green gentrification and promote urban contraction, potentiating the NBS impact. Variations of property taxes had the greatest impact on both phenomenon, while public transport subsidies might help with urban sprawl and zoning with gentrification.

While the study contributes to the urban design literature by addressing different NBS types and policy instruments, limitations exist as relocations depend on other factors that were not accounted for, as extra costs and developments. Furthermore, monitoring, costs and governance aspects regarding policy instruments implementation were not considered. Next studies should consider NBS and policy instrument mix, simulating several solutions.

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Annexes

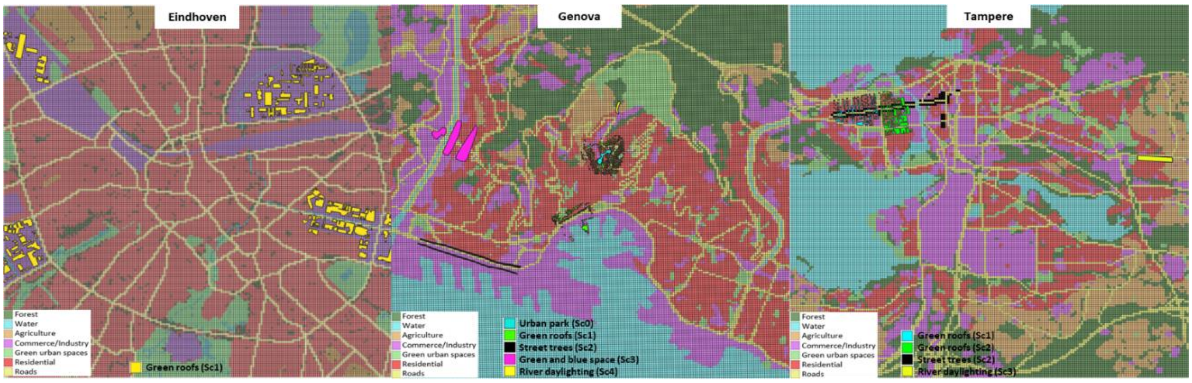

Figure 1. Land use, NBS scenarios and their locations in Eindhoven, Genova and Tampere case studies.

Table 1. NBS design characteristics.

		Attractive-ness	*Size*	*Location*	*Household type*
Green roofs	EIN	3	42 ha	Periphery	-
	TRE1	3	7 ha	Central	RES1&2
	TRE2	3	12 ha	Central	RES1&2
	GEN	3	13 ha	Central	RES2&3
Street trees	TRE	3	15 ha	Central	RES1&2
	GEN	3	4 ha	Central	RES2
Urban park		2	1.6 ha	Central	RES2
Green and blue space		1	17 ha	Intermediate	RES2&3
River daylighting	TRE	1	4 ha	Periphery	RES3
	GEN	1	0.7 ha	Periphery	RES3

Table 2. NBS simulation results, including socio-economic and land use impacts.

		Urban area	*Housing quantity*	*Housing price*	*Urban sprawl*	*Green gentrification*
Green roofs	EIN	- -	- -	+ +	- -	0
	TRE1	+ +	+ +	- -	+ +	0
	TRE2	+ +	+ +	- -	+ +	0
	GEN	-	-	+	-	0
Street trees	TRE	+	+	-	+	0
	GEN	0	0	0	0	0
Urban park		-	-	+	-	0
Green and blue space		- -	- -	+ +	- -	+
River daylighting	TRE	- -	- -	+	- -	0
	GEN	-	-	+	-	0

Table 3. Policy instruments simulation results, including socio-economic and land use impacts.

	Urban area	*Housing quantity*	*Housing price*	*Urban sprawl*	*Green gentrification*
Property tax	- -	- -	+ +	+ +	0
Linear property tax (res3)	-	-	+	+	+ +
Property subsidy (res1&2)	+	+	-	-	+
Land tax	0	0	0	0	0
Public transport subsidy (res1&2)	- -	- -	+	+ +	0
Zoning	-	-	+	+	+ +