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Embedding technologies for improving Nature-Based Solutions performance and fostering social inclusion in urban greening strategies: Augmented NBS for cities

1. Introduction

Nature-Based Solutions (NBS)[7] have been at the forefront of the European Commission policies since 2015 (Eggermont et al., 2015) as a specific thematic area for developing sustainable cities strategies either from social inclusivity or innovative urban technology standpoints (European Commission, 2023). NBS have been considered as innovative solutions within the ambition to enact a new ambit of research for NBS and implications on urban transition (Zwierzchowska et al., 2022). Nonetheless, the technological advancements related to NBS implementation are increasingly demanded in correspondence to the need to improve and mainstream NBS impacts at architectural, urban planning and strategic levels (Hölscher et al., 2023).

The experience of NBS in place has increasingly matured with many applications in practice (Mahmoud et al., 2022), which have enabled the development of new skills and related services and the refinement of new technologies and technical solutions (Wellmann et al., 2022). The technological support for NBS has become evident throughout the way people experience urban nature in their everyday lives (Ahlborg et al., 2019; Li & Nassauer, 2021).

In this special issue, the theme of technology and its uses within urban planning and green infrastructure was investigated. We promote the concept of ***"Augmented NBS"*** that is, NBS supported and enhanced by the use of technology, whether incorporated directly into the solution in the field as a prosthesis of the natural element or deployed remotely through digital analysis tools or remote sensing (Mahmoud et al., 2024). Hence, the special issue embraces a broad conceptualization of the use of technology applied **"in"** and **"for"** NBS, including digital placemaking, air quality, economic benefits, health and wellbeing, and digital mapping and decision-making tools for landscape design. It is aimed to collect best practices on how technologies, in different ways, can enhance the performance and impact of NBS. From March 2022 till July 2023, this special issue collected several articles from the socio-ecological-technological aspects and NBS themes.

2. NBS and technology

Specifically, we focused on several key questions: Can technologies augment NBS, towards a more radical symbiosis of green and digital cities? Can we benefit from measuring NBS performances for developing successful and innovative management and business models of urban green, and support sound decision-making and policy making, which is often problematic to local government? What are the multiple impacts delivered by hybrid green and digital solutions, how to measure them and eventually how to monetize them?

In particular, the following explorations around technology "**in**" and "**for**" NBS are relevant for this issue:

2.1. *Technology in Green*

Embedding technologies into NBS could increase their environmental performance and social impact: for instance, environmental sensors and IoT devices measuring the health of nature and urban biodiversity; digital displays and communication interfaces in proximity to NBS for communicating relevant messages to people; sensors for co-monitoring campaigns as part of citizen-science activities in urban greening; automated maintenance and irrigation technology solutions incorporated directly into NBS.

2.2. *Technology for Green*

Outside and beyond NBS per se, technologies can be applied to enhance the impact of NBS in cities and beyond. ICT can be used to engage citizens in co-producing and taking care of green via co-maintenance and co-monitoring. Thus, generating stronger sense of belonging and social bonds within communities, for instance with emphasis on the inclusion of marginalised and vulnerable groups. Moreover, mapping technologies such as remote sensing and LiDAR can support decision-making for planning, designing, and monitoring towards the overall progress of greener cities, contributing to assessing the global targets of the 2030 Agenda at the local scale (e.g., localizing SDGs in cities) and reporting on ESG criteria.

3. Impacts from latest research

In the first article about digital placemaking**,** health & wellbeing and NBS (Fernandez de Osso Fuentes et al., 2023) a systematic review and practice model about possible integration between community engagement and co-creation with digital placemaking to enhance smart city practices was presented. On this topic, several researchers point out that NBS and green-blue infrastructure could be linked to hybrid realities such as cyber infrastructure in cities (Freeman et al., 2019). The topic of digital placemaking and green urbanism have also been connected to research on co-creation, co-governance and collaboration in

[7] Updated definitions from UNEA-RES 5.5. ON NBS, agreed on 2 March 2022, see https://www.unep.org/environmentassembly/unea5

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city-decision-making processes, whereas technology is a tool for socio-ecological principles or for NBS design enhancement. This article is a clear example of **Technology for Green,** whereas technology devices are used outside of the NBS to measure its impacts.

The second article (Palomo Amores et al., 2023) focuses on the effect of green infrastructures supported by adaptative solar shading systems on the livability in open spaces. The research combines greenery and NBS with structural shading components to improve outdoor comfort and increase time spent outdoors. A public square in Seville is used as a pilot case where vegetation is added, while a series of measurements were performed together with fluid dynamics simulations. The modular technological solution is interesting because it represents a symbiosis of artificial and natural, a true temporary "prosthesis" structure that accompanies the development of the trees and will be removed when the canopies provide sufficient shade for the square. The analysis revealed a 21–30% decrease of discomfort hours due to the green structure and vegetation. This is a clear example of **Technology in Green** where the incorporation of the physical pergola and shading device and the sensors helped quantify the impact of NBS on outdoor comfort.

The third contribution by Semeraro et al. (2023) focuses on a decision-making framework for promoting the optimum design and planning of NBS at local scale. The authors present an application of a decision support system aiming at selecting morphology scenarios, by considering the human-nature interaction in an urban context. The methodology is based on the calculation of human thermal comfort using the microclimate model (ENVI-met) in a case study of Lecce, a city located in Southern Italy. It demonstrates how urban heat mitigation could be achieved thanks to a well-designed integration of buildings and green surfaces and community gardens, supported by the best combination between natural capital and human-derived capital. The best scenario achieves in many open spaces the target of reducing the Physiological Equivalent Temperature (PET) around 40 °C (which can be considered a critical value for strong heat stress) with an investment cost in NBS smaller than one-day hospital cost for a single person. Moreover, additional co-benefits are expected such as recreation, cultural and artistic information, science and education, etc. This article is a clear example of **Technology for Green,** whereas technology devices are used outside of the NBS to measure its impacts.

In the fourth article, Chiaffarelli and Vagge (2023) conduct a study in the peri-urban fringe of Milan, where urban-rural interface is characterized by ecological vulnerability due to conflictual land uses, anthropogenic disturbances, and the deterioration of floristic vegetational traits. Anchoring on landscape ecology studies, the two authors propose an agri-environmental analytical framework to map and understand of the ecological behaviour of peri-urban landscape features (PLFs) systems to inform their multi-functional phytocoenoses ecological reconfiguring. The study employs several digital **Technologies for Green** to map and analyse vegetative and human communities at both an agri-environmental extra-local scale and a finer scale. The analysis informs the development of a functional-dynamic interpretative approach and design criteria for corrective interventions aimed at enhancing the ecological functions and stability of peri-urban landscapes.

The fifth article by Pysander et al., (2023) of nature and digitalization challenging the traditional playground addresses the importance of nature in the health and wellbeing of children nowadays, whose playing and interaction with peers is mainly performed via screen-based activities. A merging of digital technologies with physical playground is performed and the combined role of digital artefacts, play equipment and natural elements, is investigated through the field study of children aged 6–8 in a three-week period playing in a traditional playground, a forest and in a forest with digitally enhanced play artefacts. This is a clear example of **Technology in Green**, in which through NBS and human-made artefacts supported by digital technologies to increase attractiveness, the social exchange and the playfulness of the children is intensified.

In the last article by Jones et al. (2024) on economic value of the hot-day cooling provided by urban green-blue spaces, the economic benefits from increasing Green and Blue Infrastructure (GBI) are evaluated for an overarching period of ten years (2008–2017) for eleven City Regions in Great Britain. The novelty in this study is about quantifying the economic impact of the cooling effects of a range of GBI types on air temperature and health assessment. The authors give evidence-based analysis on the possibility to predict the annual savings in energy if NBS are considered as means of cooling in urban planning in those regions. The proposed approach and methodology can be easily replicated in other contexts while considering main climatic zones where the NBS are implemented. This identifies new means for **Technology for Green**, providing direct evidence on the environmental and financial benefits of incrementing urban vegetation.

4. Summary

From the articles collection, the application of distant or incorporated technologies in urban greening strategies have diverse beneficial impacts on societal and environmental challenges. In particular, supporting the increase of nature and NBS in the urban and peri-urban settings bring several benefits to social cohesion, health and wellbeing of communities, economic benefits as well as an increased sense of ownership.

These benefits could be managed and reinforced via different channels using **Technology for Green**. Firstly, digital participation and tools to support the co-design and co-creation processes of NBS have demonstrated great potential in diffusing and mainstreaming NBS in urban settings. Secondly, it is fundamental to recognize the relevance of monitoring and evaluation of the impact of NBS on communities and biodiversity. For instance, the design assessment methods and post-occupancy evaluation methods used for NBS implementation in public spaces can benefit from social media and several instruments of information exchange and for bonding social relationships in local communities.

On the other hand, concerning **Technology in Green**, we can distinguish two main purposes: namely, to support the vegetative species themselves employed in NBS on the one hand, and for the benefit of humans on the other. In the first case, it is an approach that partly abandons the anthropocentric perspective and looks at nature for nature's sake, that is, the support that technology can give vegetative species to survive. We talk about survival, since in urban settings the suboptimal conditions and constraints derived from many NBS (e.g., non-rooting of plants on the ground, sun exposure at unsuitable and non-spontaneous orientations), force the plants into continuous stress. Hence, environmental, moisture sensors embedded in or near the plants enable monitoring of plant health. We have no examples of this in our collection, which focuses instead on benefits to humans. Modular pergola systems that accompany growing trees to provide shading opportunities, digital devices in urban parks to encourage contact with nature and greater attendance, although instrumental to human comfort and well-being, could generate greater sensitivity and awareness towards and for nature.

In conclusion, we argue that there is a need to develop a taxonomy of "***Augmented NBS***", in order to identify with greater clarity and greater awareness the role of technology in supporting nature for nature, or for humans, as happens in most cases and as evidenced by the six articles in this collection. The application of NBS is now mature, and scholars and practitioners should generate more research on the costs and benefits of the use of technology in terms of return on investment, payback time, and supporting maintenance. Finally, a deeper integration of NBS and related technologies in the conceptualization of urban design regeneration projects and planning decision-making themselves is needed, to avoid treating greenery as a mere add-on to the urban environment.

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