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Sustainable Smart Park Management—A Smarter Approach to Urban Green Space Management?

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Abstract. In parallel with ongoing discussions on what the concept of a smart city actually entails, use of smart technology in management and governance of urban green space is increasing. Application of smart technologies usually involves multiple sensors, smartphones, internet connections, etc., working together to make green space management more inclusive and effective. In the Sustainable Smart Parks project in Gothenburg, Sweden, new technologies are being applied and tested for availability, reliance, and relevance for contemporary management. However, moving these technologies beyond ad-hoc applications and creating a joint systems approach to future management is still unexplored. In this article, we introduce an analytical framework based on urban ecology and nature-based thinking and use it to examine the Sustainable Smart Parks initiative. The framework works well in distinguishing integration of diversity, connectivity, adaptation, inclusion, and perception in different technologies. However, further studies are needed to test adequacy of the 5 initial criteria in a wider context and to increase coupling of smart technologies that share similar focus within each criterion. This would stimulate "systems mapping" and thus clearer progression toward integrated smart green space management.

Keywords. Governance; Green Infrastructure; ICTs; Nature-Based Thinking; Smart City; Urban Ecology; Urban Forest; Urban Green Space; Urban Trees.

INTRODUCTION

The digital landscape of information and communication technologies (ICTs) is an important dimension of the smart city concept (Anthopoulos 2017; Allam and Dhunny 2019). However, research has shown that smart city adoption can be somewhat ambivalent, and that use and interpretations are decided by the user (e.g., government organizations, business corporations, and/or researchers)(Anthopoulos 2017). Past research on smart cities has attempted to define what the term "smart" might embrace and how it could be interpreted (Albino et al. 2015; Kummitha and Crutzen 2017; Colding et al. 2020a; Grace et al. 2021). Other research has critically assessed the concept and identified differences from other concepts, e.g., "sustainable city development," "resilient city," and "knowledge city" (de Jong et al. 2015; Ahvenniemi et al. 2017). An extensive review by Mora and Deakin (2019a, 2019b) summarizes contemporary critiques on whether the smart city represents a new episode in the "context of utopian urbanism" and draws parallels to previous illusions and utopian thinkers, such as Sir Ebenezer Howard and Le Corbusier. Reported tensions and disadvantages include shortcomings in confronting dominant consumerist cultures, an increase in neoliberal economic growth, and target groups often consisting of citizens with higher socio-economic status (Martin et al. 2018; Colding et al. 2019), potentially excluding less privileged citizens (Gulsrud et al. 2018). Other critics claim that the smart city approach is a top-bottom intervention and a company-driven product, with corporate and political interests benefiting the most (Albino et al. 2015; Kummitha and Crutzen 2017). Further, the complex of interconnected systems and information, where various algorithms translate activities into data (staff working tempo, transport, activities, product placements, etc.), poses novel challenges to risk management and security (Jennings 2010; Colding et al. 2020a).

Nevertheless, while conventional planning is concerned chiefly with "visions" for future needs, the smart city approach could help improve the connectivity of social-ecological-technological exchanges and governance frameworks in delivering transferable information and "co-design methods," with genuine returns on investment for all stakeholders involved (Grace et al. 2021). Beneficial effects of the smart city approach include fostering citizen-focused approaches and adaptive policy making (Ben Yahia et al. 2021), providing data-led solutions and interactions (Viale Pereira et al. 2018), and increasing prestige for the city itself and its politicians (Parks and Rohracher 2019).

Despite prospective benefits of the smart city approach, its relation to ecological and environmental dimensions is often overlooked (Colding and Barthel 2017). The most prevailing criticism is lack of integration at the interface of smart digital technology and environmental protection (Grace et al. 2021). A recent review of publications on smart cities found that only 6.6% concerned environmental dimensions, with a clear dominance of social and technological dimensions (Colding et al. 2020b). While application of smart technology can support deeper learning and time efficiency in urban green space management, there are concerns about its impact on existing arrangements of power, human relations to ecological systems, and governance, since rules, routines, and institutional arrangements will "iteratively be shaped by technological advancements and social practices" (Gulsrud et al. 2018). This goes hand in hand with the ad hoc process of data accumulation, where a cohesive framework for individual applications is lacking. As Ramaswami et al. (2016) point out, concerns arise when huge amounts of data are generated for their own sake, rather than improving understanding of cities as transboundary, multisectoral, multiscalar, social-ecological systems. We ask whether current development of smart technology in urban green space management reflects this difficulty and whether applications of various technologies have been sufficiently reviewed as regards gaining an integrated and comprehensive understanding of the joint effect on governance and organizational prospects and on collective cognition of how urban nature and ecosystems operate.

Theoretical Foundations: Urban Ecology and Nature-Based Thinking

Urban ecology combines studies on social-ecological systems, resilience, and ecosystems, focusing on planning and decision-making, and uses knowledge of spatiotemporal patterns and social-ecological interactions in the urban landscape to help guide future urban sustainability (Steiner 2014). By considering ecological footprint and the role of ecosystem services, urban ecology recognizes the importance of viewing urban landscapes as complex adaptation systems involving nonlinear dynamics, feedbacks, and unforeseen events (McPhearson et al. 2016a). In this perspective, the web of green infrastructure, i.e., all vegetation, water, and permeable soil within urban landscapes, becomes a natural coping network that helps respond to internal and external disturbances (Tzoulas et al. 2007). Illustrative examples are those of climate mitigation and adaptation, where green infrastructure plays a decisive role, e.g., in carbon storage and sequestration, stormwater mitigation, urban cooling, and air pollution reduction (Pauleit et al. 2017). However, the quality and capacity of ecosystem functions and services rely heavily on human intervention, i.e., how natural capital is managed and cared for (Haines-Young and Potschin 2010) and how public perception and attitudes to outdoor environments and urban green space influence management decisions (Jansson et al. 2020). How technology and digital innovation fit into this framework is a major consideration in the recent discourse within urban ecology on recognizing cities as "triple-connected" social-ecological-technological systems (SETS)(Frantzeskaki et al. 2021).

The nature-based thinking approach proposes that ecological, economic, and community dimensions are interlinked in nature and natural processes (Randrup et al. 2020). This allows for space, continuous change, diversity, long-term uncertainties, and buffering capacities within management strategies, requiring deconstruction of conventional organizational divisions within planning, design, and management. It recognizes the challenge of temporal differences between the pace of natural processes and that of organizational management in different rhythmical sequences (Randrup et al. 2020). Most local government organizations concentrate on short-term gains and essential maintenance operations, and they make insufficient resources available for long-term governance and management (Randrup et al. 2017), whereas natural processes require a time horizon of decades to centuries (Holling 2001). The conventional linear logic of planning, design, construction, and maintenance needs to be reassessed through nature-based thinking; it needs to become long-sighted and holistic, and accommodate different governance structures where diverse municipal organizations, contractors, and stakeholder groups participate (Potschin-Young et al. 2018).

This may seem a complex task, but nature-based thinking should not be seen as a rigid discipline, as there is no single solution to sustainable and resilient cities (Keeler et al. 2019; Grace et al. 2021). Rather, it provides a range of opportunities where smart technology can improve understanding of natural processes on nature's conditions, involve and attract communities and individual citizens, and find joint and transferable values of natural capital between different stakeholders. With pressing concerns about climate change and loss of biodiversity, integrating ecological dimensions into the "smart city" approach is critical. For this, theories in urban ecology (McPhearson et al. 2016b) and nature-based thinking (Randrup et al. 2020) can provide a supporting framework.

THE SUSTAINABLE SMART PARK MANAGEMENT (SSPM) FRAMEWORK

To examine whether existing smart technologies applied in green space management can provide a holistic overview of ecological, technological, economical, and organizational aspects, we developed an analytical framework for Sustainable Smart Park Management (SSPM) based on urban ecology (Steiner 2014), and nature-based thinking (Randrup et al. 2020)(Figure 1).

The SSPM framework analyzes 5 criteria: (1) diversity, (2) connectivity, (3) adaptation, (4) inclusion, and (5) perception.

Diversity

Urban ecology has a strong focus on planning, decision-making, and using knowledge of diversity in organisms, heterogeneity of space, and the diversity of social-ecological interactions that feed back to one another to help guide future urban sustainability (Pickett and Cadenasso 2017). Diversity and heterogeneity "sustain the system's adaptive capacity to compensate for losses," while human interventions aiming to increase "the frequency of the most optimal ideas" and activities may contribute to diversity loss (Levin et al. 2013). Hence, including smart technology in green space management should provide a picture of the diversity of organisms and processes (different green space components, ecological organisms, heterogeneity of space, different user groups and their interrelationships), and thus provide guidance toward a diversity of actions within green space management.

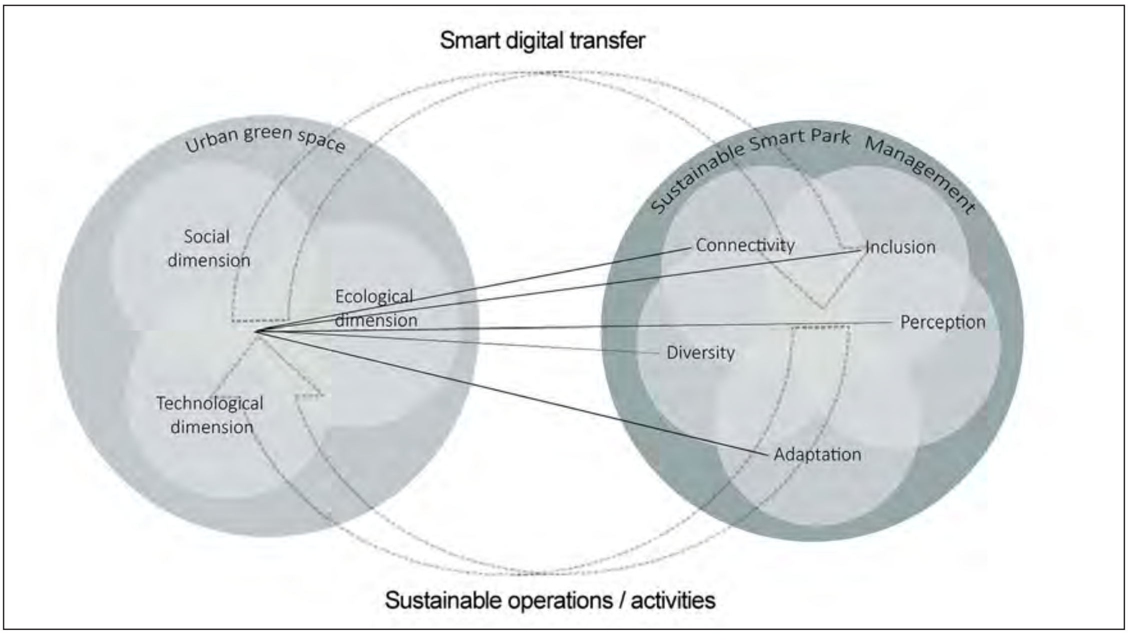

Figure 1. The conceptual framework of the Sustainable Smart Park Management approach projecting from the theories of urban ecology and nature-based thinking where smart technologies are analyzed through the lenses of diversity, connectivity, adaptation, inclusion, and perception as to provide a holistic advance to sustainable operations in the management and maintenance of urban green space.

Connectivity

Inclusion of social dimensions, resilience, and a complex systems approach is embraced in nature-based thinking, which recognizes the need to build connectivity between cyclical and long-term processes, allowing space for "nature" to develop; to apply a nature-based approach in cross-sectoral management and maintenance; and to involve citizens in the process (Randrup et al. 2020). To improve understanding of the interconnectedness between users and urban green spaces, smart technologies should increase the connectivity between different sectoral groups, companies, and user groups. Different technological devices could also be connected to reveal the interconnectedness between different elements of vegetation, soil, water, etc., providing a holistic approach to maintenance of ecological processes and producing transferable information for different stakeholders. Connectivity is thus projected from social-ecological, technical-ecological, and social/organizational-technical processes (Gulsrud et al. 2018).

Adaptation

An inherent dimension to resilience is the capacity of a system to adapt to changing and often unforeseen conditions while still continuing to operate without losing fundamental functions (Levin et al. 2013). Adaptation in urban landscapes is linked to different types of continuity between social-ecological factors and biocultural diversity (Andersson and Barthel 2016) and "learning by doing," e.g., recognizing failure as vantage points and guidance (Ahern et al. 2014). In this perspective, memory becomes an asset to adaptation and resilience, as "memory banks" can help delineate different ecological and social memory carriers (Andersson and Barthel 2016). Smart technology can increase adaptation capabilities by monitoring external and internal perturbations occurring in ecological processes, allowing lessons learned to be incorporated into green space management, and enabling a better understanding of feedbacks and adaptation. Smart technology should also aim to support adaptive capacity within social and organizational systems, foster cross-sectoral knowledge building, and help delineate changes in attitudes and interactions amongst visitors and user groups.

Inclusion

Urban green space management applies a long-term perspective to planning, design, construction, and maintenance (Jansson et al. 2018). Although the focus of management is essentially inclusion of different user groups (Jansson and Lindgren 2012; Dempsey and Smith 2014), management for the benefit of nature and ecological processes (Randrup et al. 2020) and to meet the emerging need for participation of different user groups in more horizontal governance structures (Jansson et al. 2020) is also important. Ecological/green space inclusion emerges from the views and perceptions of user groups (Martin et al. 2018; Colding et al. 2019), so inclusion of user groups' perceptions on green space and "quality" may trigger different management actions, such as less maintenance of certain areas. Smart technologies thus embody green space inclusion (i.e., all green space for ecological processes matters) and user group inclusion (i.e., all views and values of different user groups matter). Data sharing (open data) may increase collective intelligence and user participation in governance, and it may even lead to more inclusive modes of governance, e.g., mosaic governance (Buijs et al. 2019).

Perception

Applying nature-based thinking in management will inherently require new perceptions of (urban) nature from esthetic, temporal, and organizational perspectives (Randrup et al. 2020). The links between esthetics and ecological processes are vital to green space management. Humans engage with nature at a different scale from ecological processes and environmental phenomena and, within this smaller "perceptible realm," esthetic experiences occur, influenced by different contexts that range from landscape type and activities performed to personal and social situations (Gobster et al. 2007). We suggest that use of smart technologies could lead to increased understanding and awareness of urban green space as "nature" and natural processes occurring in landscapes for all stakeholder groups (from government agencies to individual citizens). This accommodates long-sighted cyclical approaches in the management of ecological processes, reaching beyond conventional timescales of public management to envision space making and place making for ecological processes, and creating a biophilic relationship between urban citizens and urban nature.

The Definition of "Smart"

We define "smart" as in Mora and Deakin (2019b), where digital technology and innovation are seen as vehicles toward urban sustainability that also play a fundamental part in “tackling environmental degradation and fighting climate change…grounded in collective intelligence, bottom-up actions, participatory governance, open and user-driven innovation, and community led urban development” (Mora and Deakin 2019b). Smart digital infrastructures also need to be “nurtured and maintained as they materialize in particular places” (Evans et al. 2019). “Smart” thus implies possible means toward achieving sustainability in and of urban landscapes with the inclusion of digital technology and ICT approaches, where “sustainability” is defined as in the Brundtland Report (1987): “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (Borowy 2014).

MATERIALS AND METHODS

We tested our new SSPM framework in the Sustainable Smart Parks (SSP) project, where various smart technologies for green space management are being applied in the city of Gothenburg, Sweden. To gain a clear understanding of the contributions of these smart technologies, we initially focused on their actual contribution within their technical boundaries. We did not consider potential outcomes if the appliances were coupled or linked to other smart technologies, but rather we delineated each device to identify potential blind spots or voids and possibilities for integration in a holistic management approach.

In the SSPM framework, each of the 5 criteria (diversity, connectivity, adaptation, inclusion, perception) includes 2 to 3 subcategories to further delineate potential outcomes and effects of the smart technologies within the social-ecological-technological dimension. Each smart technology was assessed against these categories based on its current application in the SSP project (Appendix Table S1).

The Gothenburg Smart City Approach

Gothenburg, the second largest city in Sweden (population 533,000), is at the forefront in applying and testing the smart city approach through digital innovation. The city is involved in several research and development programs at different scales funded by several government organizations. One of the larger ventures is the HORIZON 2020 EU-funded IRIS project (2017) which aims to transform Gothenburg into a “Lighthouse City” and test bed of innovative energy and mobility solutions with districts of Living Labs (e.g., Marvin et al. 2018) in collaboration with multiple actors. Other projects are the City as a Platform (RISE 2018), which aims to “explore, test, implement open Internet of Things (IoT) platforms to support community benefits in the cities,” and Virtual Gothenburg (RISE 2019), an initiative by the city’s Urban Planning Division in collaboration with several research institutes to develop a digital twin city to benefit future planning. The overall aim is to disclose existing and prospective open data, empowering citizens to contribute to collective intelligence and visually forecast future events as an incentive for climate adaptation (Mora and Deakin 2019b). The ongoing smart initiatives in Gothenburg reflect the city’s ambition to embrace a future where smart digital technology is an important tool in sustainable urban development (UNECE 2021).

The Sustainable Smart Parks Project, Gothenburg

Sustainable Smart Parks (initiated 2008) aims to create an open and innovative arena for the development of future smart green spaces, increase the recreational value of urban green space, and support a sustainable approach to minimize negative environmental impacts in green space management and maintenance. SSP, which invites actors interested in exploring new ideas and concepts of digital investments in real-life environments, is a collaboration between several departments within the City of Gothenburg, private companies, and manufacturers (Husqvarna AB), with the Swedish University of Agricultural Sciences coordinating research interests.

Digitalization and automation in the green space realm can allow data from digital appliances to help optimize organization and performance for future design and management, focusing on function and actual demand, rather than predefined operational frequencies (e.g., number of times a lawn should be mown) or fixed outputs (e.g., how high a lawn is allowed to grow before next mowing)(Figure 2). Digitalization and automation will involve citizens through smartphone connections, where they can map their perceived recreational values of specific urban green spaces.

The SSP project is similar to many other international smart technology projects exploring means of coordinating incoming data, while inviting more applications of further interest. Current and planned data collection includes information from maintenance

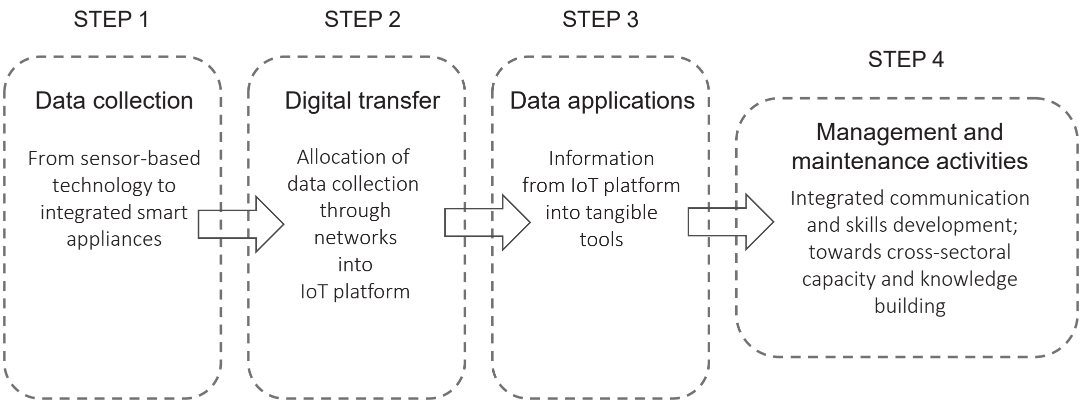

Figure 2. A conceptual diagram of the process of smart approaches to smart technology in green space management and maintenance. Collected data from various sources (step 1) is transferred digitally (e.g., via 4G, 5G, or LoRa)(step 2) to be transferred and integrated into specific data applications (step 3) as basis for an integrated approach toward management and maintenance operations (step 4).

machinery and sensors monitoring soil moisture and interactions with visitors. There are many issues, both technical and managerial, to be resolved regarding how to respond to data collected and presented in the applications. For example, the moisture level recorded by tree soil sensors could be transferred via a 5G network to a database and used to produce a diagram of moisture levels over time, and managers could use this diagram to plan irrigation. Technically, this could involve further complexity if the data triggered additional operations, requiring an overarching approach to forthcoming maintenance (Figure 2).

RESULTS

Application of our SSPM framework (Table 1) to the SSP project yielded the following results for the 5 criteria.

Diversity primarily relates to specific types of ground and remote sensors providing information related to green space components and ecological organisms, but it also refers to heterogeneous qualities in different areas. Smartphone applications to engage users and different stakeholder groups also provide pictures of diversity, e.g., the diverse attitudes and experiences related to different green spaces that likely influence use of different places. Visitor interactions through mobile applications capture a diversity of viewpoints and experiences related to other stakeholders and user groups.

Connectivity primarily relates to sensors generating technological-ecological aspects, where ground sensors and remote sensors help explain the interconnectedness of different elements and how this information is determined by technological instruments. Connectivity of social/organizational processes is primarily linked to fleet equipment to support organizational processes through logistic intelligence and to visitor monitoring where the frequency of visits interconnects to management regimes. This more integrated approach to mobile applications increases understanding of the interconnectedness between users and urban green space, and it also delineates connectivity between different stakeholders and user groups.

Adaptation within ecological systems primarily relates to ground and remote sensors that monitor perturbations occurring in ecological processes, e.g., changes in species diversity, soil moisture, temperatures. Fleet equipment and smart applications to engage visitors support cross-sectoral knowledge building and allow changes in attitudes and interactions to influence transformation of green space into adaptive place making and management strategies.

Inclusion of green space and ecological processes relates to ground and remote sensors providing insights into ecological matters by contextualizing ecological processes as place-specific yet part of a larger system. In terms of social inclusion of different user groups and horizontal governance approaches, integrated applications for visitor interaction in mobile devices provide insights into how different user groups contribute open data to collective intelligence, helping to delineate differences of appreciation for different places.

Perception of the longitudinal time frame of ecological processes relates to ground and remote sensors providing insights into potential place-making approaches in novel contexts and the correlation and timing of maintenance operations. Perception of place making is also captured to some extent by automated maintenance (e.g., automated lawn mowing), as it influences new space and place making. Perceptions fostering biophilic relations are supported by interactive devices connecting urban citizens to different green spaces.

The overall analysis illustrated that integrated smart devices which obtain qualitative information from visitors cover most subcategories related to social-ecological-technological dimensions within each criterion. Sensor-based technology (ground sensors for soil moisture and remote sensors for plant identification) cover most criteria, in contrast to automated maintenance, fleet equipment, and visitor monitoring relating to frequency of visits. Sensor-based technologies, providing mostly quantitative data, are less likely to

Table 1. The table shows the analytical mapping of the different approaches of smart technology (ST) within the Sustainable Smart Parks project in Gothenburg, Sweden, based on criteria from urban ecology and nature-based thinking. For each 5 criteria, there are 2 to 3 subcategories to help examine how the different ST approaches relate, which may provide a deeper understanding of dimensions of urban ecology and nature-based thinking. The analysis connected each ST device to the actual contribution it is making within its technical boundaries, i.e., the analysis does not consider potential outcomes if the appliance is coupled or linked to other STs, but identifies what it is actually providing in its own right.

	Diversity	Connectivity	Adaptation	Inclusion	Perception
	○ of ecological organisms ◌ heterogeneity of space ● of interactions between stakeholders	○ of social-ecological processes ◌ of technical-ecological processes ● of social/ organizational-technical processes	○ within ecological systems ◌ within organizational systems	○ ecological (all green space matters) ◌ social (of user groups and horizontal governance)	○ of longitudinal time of ecological processes ◌ of place making ● toward biophilic relations
Sensor-based technology					
Ground sensors (e.g., sensing soil moisture)	○ ◌	◌	○	○	○ ◌
Automated maintenance (sensing frequency and location)					◌
Fleet equipment (sensing connection of logistics)		●	◌		
Visitor monitoring (sensing number of visits)		●			
Remote sensors used for plant identification	○ ◌	◌	○	○	○ ◌
Integrated smart appliances/devices					
Visitor interaction (e.g., mobile applications)	○ ◌ ●	○ ●	◌	○ ◌	◌ ●
IoT platform	○ ◌ ●	○ ◌ ●	○ ◌	○ ◌	○ ◌ ●

provide substantial information on social and organizational processes. The only technology providing information relating to those dimensions is fleet equipment, which aims to coordinate logistics between vehicles and fleet drivers, from where it is possible to gain information that can promote adaptation within organizational systems. The IoT platform, which in effect assembles all data from the devices, complies with all subcategories of all criteria.

Some smart technologies cover similar criteria and subcategories, e.g., connectivity of social and organizational processes is covered by fleet equipment, visitor monitoring, and visitor interaction; inclusion of ecological processes and elements by ground sensors, remote sensing, and visitor interaction; perception of place making by ground sensors, automated maintenance, and remote sensors for visitor interaction. These couplings provide an interlinked map for achieving a joint outcome from the different applications in future smart urban green space management.

DISCUSSION AND CONCLUSIONS

The SSP in Gothenburg provides a truthful profile of how most smart city initiatives progress, i.e., as an ad hoc process introducing different smart technologies and products in tandem with growing interest from the public and private companies. SSP is a test bed for learning and growing that uses a critical incremental approach of trial and error to “safe-to-fail” (Ahern 2014). However, it lacks a cohesive foundation for combining these applications into a comprehensive whole of social and ecological dimensions and for integrating each technology into a joint source of information on natural and ecological processes in order to guide future management and daily maintenance (Galle et al. 2019; Nitoslawski et al. 2019).

Our new SSPM framework, which is based on urban ecology and nature-based thinking concepts, helped reveal how different smart technology devices and approaches in the SSP project in Gothenburg could be combined to provide different stakeholder groups with a deeper understanding of SETS. In this pilot project, each technology applied has a clear role as an integrated component within a larger system. However, analysis using our framework showed that application of various technologies appears ad hoc and fragmented, as well as a general lack of focus on social and organizational processes. The SSPM framework accurately distinguished between integration of diversity, connectivity, adaptation, inclusion, and perception in the various technologies. Further studies are needed to test more diverse applications and to establish whether the 5 criteria identified are sufficient in a wider context. Analysis of visitor interactions (based on mobile applications) illustrated high potential for outreach and integration of stakeholders. However, this assumes that users forward their opinions to a receptive management organization, which is unambivalent when returning information to visitors, e.g., about nature, ecological processes, and characteristics revealed through smart technologies. This can be paramount for fostering biophilic relations among different user groups (Gobster et al. 2007; Beatley and Newman 2013) and tolerance toward different green space qualities based on different maintenance regimes. Inequality can arise in determining who stands to benefit from urban nature (Keeler et al. 2019) and in inclusion of different user groups, which is the foundation for long-term resilience of social-ecological interactions (Martin et al. 2018). Such inequality can be linked to fleet equipment such as monitoring of intelligent logistics and time efficiency, which may support unethical working conditions for employees, or to automation of maintenance operations, which may cause unemployment for staff rather than intended redeployment to qualitative maintenance tasks (Gulsrud et al. 2018). Sensor technologies for monitoring soil moisture, plant identification, water temperature, etc., can be stored in memory banks to help navigate perceptions of time and of anticipated perturbations, which are of paramount interest in supporting memory carriers within management (Andersson and Barthel 2016), but outcomes rely on who is interpreting the data.

This analysis concentrated solely on the actual contribution of each device in the SSP project, but the results indicated potential for their use in an interconnected context through the capacity to further couple smart technologies that share similar subcategories within each criterion. This would stimulate “systems mapping,” creating further interlinkages between the different applications and strengthening progress toward integrated and smart urban green space management. The analytical framework could thus be of benefit when incorporated in data application (step 3 in Figure 2) prior to steps 1 and 2, making the process of data collection and digital transfer more meaningful and directed toward a comprehensive purpose. It would also provide managerial organizations with a tangible structure and transferable values that could, for example, assist in cross-sectoral governance and governance leading the technology, and not vice versa.

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Résumé. Parallèlement aux discussions en cours sur ce que recouvre réellement le concept de ville intelligente, le recours à des technologies intelligentes pour la gestion et la gouvernance des espaces verts urbains se développe de plus en plus. L'application de technologies intelligentes implique généralement plusieurs capteurs, des téléphones intelligents, des connexions Internet, etc., qui opèrent ensemble afin de rendre la gestion des espaces verts plus inclusive et efficace. Dans le cadre du projet Sustainable Smart Parks à Göteborg en Suède, les nouvelles technologies sont appliquées et testées pour leur disponibilité, leur fiabilité et leur pertinence en gestion moderne. Cependant, la possibilité de faire évoluer ces technologies au-delà des applications ad hoc et créer une approche systémique commune pour la gestion future est encore inexplorée. Dans cet article, nous introduisons un cadre analytique basé sur l'écologie urbaine et la réflexion fondée sur la nature et l'utilisons pour analyser l'initiative Sustainable Smart Parks. Le cadre fonctionne bien pour distinguer l'intégration de la diversité, de la connectivité, de l'adaptation, de l'inclusion et de la perception sous différentes technologies. Toutefois, d'autres études sont nécessaires pour vérifier l'adéquation des cinq critères initiaux dans un contexte plus large et accroître le couplage de technologies intelligentes partageant des objectifs similaires pour chaque critère. Cela stimulerait la "cartographie des systems" et encouragerait une progression plus claire vers une gestion intelligente et intégrée des espaces verts.

Zusammenfassung. Parallel zu den laufenden Diskussionen darüber, was das Konzept einer intelligenten Stadt eigentlich beinhaltet, nimmt der Einsatz intelligenter Technologien bei der Verwaltung und Steuerung städtischer Grünflächen zu. Die Anwendung intelligenter Technologien umfasst in der Regel mehrere Sensoren, Smartphones, Internetverbindungen und andere, die zusammenarbeiten, um die Verwaltung von Grünflächen integrativer und effektiver zu gestalten. Im Rahmen des Projekts "Sustainable Smart Parks" in Göteborg, Schweden, werden neue Technologien angewandt und auf ihre Verfügbarkeit, Zuverlässigkeit und Relevanz für ein zeitgemäßes Management getestet. Es ist jedoch noch nicht erforscht, wie diese Technologien über Ad-hoc-Anwendungen hinausgehen und einen gemeinsamen Systemansatz für das künftige Management schaffen können. In diesem Artikel stellen wir einen analytischen Rahmen vor, der auf der Stadtökologie und dem naturbasierten Denken basiert, und verwenden ihn, um die "Sustainable Smart Parks"-Initiative zu untersuchen. Der Rahmen funktioniert gut bei der Unterscheidung der Integration von Vielfalt, Konnektivität, Anpassung, Einbeziehung und Wahrnehmung in verschiedenen Technologien. Es sind jedoch weitere Studien erforderlich, um die Angemessenheit der fünf anfänglichen Kriterien in einem breiteren Kontext zu testen und die Verknüpfung von intelligenten Technologien, die innerhalb jedes Kriteriums ähnliche Schwerpunkte haben, zu verbessern. Dies würde ein "System-Mapping" und damit eine klarere Entwicklung hin zu einem integrierten intelligenten Grünflächenmanagement fördern.

Resumen. En paralelo con las discusiones en curso sobre lo que realmente implica el concepto de ciudad inteligente, el uso de la tecnología inteligente en la gestión y gobernanza de los espacios verdes urbanos está aumentando. La aplicación de tecnologías inteligentes generalmente implica múltiples sensores, teléfonos inteligentes, conexiones a Internet, etc., que trabajan juntos para hacer que la gestión de espacios verdes sea más inclusiva y efectiva. En el proyecto Sustainable Smart Parks en Gotemburgo, Suecia, se están aplicando y probando nuevas tecnologías para determinar su disponibilidad, dependencia y relevancia para la gestión contemporánea. Sin embargo, todavía no se ha explorado mover estas tecnologías más allá de las aplicaciones ad-hoc y crear un enfoque de sistemas conjuntos para la gestión futura. En este artículo, presentamos un marco analítico basado en la ecología y en la naturaleza y lo utilizamos para examinar la iniciativa de Parques Inteligentes Sostenibles. El marco funciona bien para distinguir la integración de la diversidad, la conectividad, la adaptación, la inclusión y la percepción en diferentes tecnologías. Sin embargo, se necesitan más estudios para probar la adecuación de los 5 criterios iniciales en un contexto más amplio y para aumentar el acoplamiento de tecnologías inteligentes que comparten un enfoque similar dentro de cada criterio. Esto estimularía el "mapeo de sistemas" y, por lo tanto, una progresión más clara hacia la gestión integrada de espacios verdes inteligentes.

Appendix 1.

Table S1. Applications of sensor-based technology and integrated devices, i.e., smartphone applications, are delineated of their attributes and purpose and subsequently assessed in the SSPM framework. The framework includes the 5 criteria of (1) diversity, (2) connectivity, (3) adaptation, (4) inclusion, and (5) perception, with 2 to 3 subcategories further delineating potential outcomes and effects of the smart technologies within the social-ecological-technological dimension.

			Diversity	**Connectivity**	**Adaptation**	**Inclusion**	**Perception**
	Attributes of devices	**Purpose of devices**	○ of ecological organisms ◌ heterogeneity of space ● of interactions between stakeholders	○ of social-ecological processes ◌ of technical-ecological processes ● of social/ organizational-technical processes	○ within ecological systems ◌ within organizational systems	○ ecological (all green space matters) ◌ social (of user groups and horizontal governance)	○ of longitudinal time of ecological processes ◌ of place making ● toward biophilic relations
Sensor-based technology							
Ground sensors (e.g., sensing soil moisture)	Sensors to measure status of, e.g., irrigation, fertilization	To increase resource efficiency (e.g., saving water) and decrease environmental impact	○ Provides indications of the diversity of ongoing processes ◌ Renders a picture of heterogeneous qualities in different areas	◌ Explains the inter-connectedness between different elements of vegetation, soil, water, etc., and how this information is determined by technological instruments	○ Monitors perturbations occurring in ecological processes	○ Helps contextualize ecological processes as place-specific yet part of a larger system	○ Helps influence timing of maintenance operations in correlation to ecological processes ◌ Influences new space and place making for ecological processes
Automated maintenance (sensing frequency and location)	Autonomous technology like auto-mowers to increase efficiency in personnel and energy	To make maintenance operations more efficient in terms of decreasing energy consumption and pollution as well as time spent by staff					◌ Influences new space and place making for ecological processes

Table S1 continued on next page

Table S1. Continued.

	Attributes of Devices	Purpose of Devices	Diversity	Connectivity	Adaptation	Inclusion	Perception
Fleet equipment (sensing connection of logistics)	Telematics-based equipment for collection of machine-use data (runtime, transport, position, etc.)	To optimize number and types of machines to increase efficiency and resource use, as well as to optimize the management of operations		Helps support organizational processes through logistic intelligence	Allows for cross-sectoral capacity and knowledge building		
Visitor monitoring (sensing number of visits)	Measure number of user visits	To study which areas are used by visitors		Helps indicate frequency of visits and how this in turn connects to management and maintenance			
Remote sensors used for plant identification	Remote sensing for plant species identification and distribution	To measure and evaluate species diversity	Renders a picture of the diversity of green space components Renders a picture of heterogeneous qualities in different areas	Explains how the information on species diversity is determined by/connected to technological instruments	Monitors changes in diversity	Helps identify areas/places sensitive or robust to biodiversity	Helps discern changes within populations on a temporal scale Influences new space and place making for ecological processes

Table S1. Continued.

	Attributes of Devices	Purpose of Devices	Diversity	Connectivity	Adaptation	Inclusion	Perception
Integrated smart appliances/ devices							
Visitor interaction (e.g., mobile applications)	Measure performance quality experienced by users via digital polls	To study which areas are appreciated by users	Contributes a diversity of viewpoints and experiences by visitors toward ecological organisms/ green space components Helps map the use of different places Captures a diversity of viewpoints and experiences related to other stakeholder and user groups	Supports an increased understanding of the interconnectedness between users and urban green space Contributes to an increased connectivity between different stakeholders	Delineates changes in visitors' attitudes and interactions	Helps map the differences of appreciation of different green spaces Includes a variety of different user groups and data sharing (open data) contributing to collective intelligence	Influences new space and place making for ecological processes Contributes to biophilic relations of urban citizens and urban nature
IoT platform	Collection and storage of technical information from machines, sensors, and observation equipment, as well as operating systems for planning and steering	To enable optimization by combining information from different systems and organizational units; more efficient data treatment in general	Provides an assemblage of data on a wide range of ecological diversity generated from ST appliances Provides an assemblage of data mapping the use of different spaces and heterogeneous qualities in different areas Helps render a diversity of viewpoints and experiences related to all stakeholders	Provides access to diverse sets of data which might be useful for understanding social-ecological relations Provides interconnectedness between various ST appliances and how they render ecological processes Helps promote nonlinear connectivity and communication between stakeholders and within management organizations	Provides access to ecological monitoring to help identify adaptive capacities Allows for organizational cross-sectoral capacity and knowledge building	Provides access to ecological monitoring to help systemize green space qualities to, e.g., user groups and maintenance operations Includes a variety of different user groups and data sharing (open data) contributing to collective intelligence	Provides access to ecological monitoring to better understand the temporal mechanisms of ecological processes Supports an increased understanding and awareness in all stakeholder groups Supports information leading towards biophilic relations