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The Emergence of Smart Urban Forestry: Challenges and Opportunities in the Digital Age

By Sophie Nitoslawski and Cecil C. Konijnendijk

The past couple of years have proved exceptionally challenging for urban professionals and practitioners, as cities around the world faced a pandemic and subsequent demand for and pressure on green spaces (Venter et al. 2020), all the while dealing with extreme climate events. The impacts of the climate crisis particularly came to the fore in the summer of 2021. Western North America and other parts of the world experienced dangerous and unprecedented heat waves (Berardelli 2021; Cappucci 2021). Wildfires raged in Northern Africa and Southern Europe (Chow 2021). Intense flooding caused major destruction in Western Europe and China (Hassan 2021). These events are inextricably linked to policy and management decisions related to urban trees and forests; not only is urban vegetation affected by climate change, but it also contributes to mitigation and adaptation efforts and provides essential, varied, and wide-ranging benefits to urban populations (Brandt et al. 2016).

It is also becoming clear that this age of the Anthropocene will be a digital one. Research in earth sciences, ecology, and conservation has suggested that shifts towards more ubiquitous digital practices in recent years are occurring to support environmental data collection, monitoring, and management practices—and (urban) forestry is no exception (Arts et al. 2015; Zou et al. 2019; D'Urban Jackson et al. 2020; Salam 2020; Nitoslawski et al. 2021). In the urban context, smart-cities research has evolved to not only focus on technological applications, but also reflect on the importance of social capital, equity, and ecosystem resilience to support truly sustainable cities (Colding and Barthel 2017; Trencher 2019; Yigitcanlar et al. 2019). Green infrastructure and urban forests, along with their associated benefits for urban citizens, will no doubt feature prominently in these discourses. The increasing interest in digital and remote applications in urban landscape management, likely accelerated by the pandemic, is engendering questions about varied roles and emerging applications for digital technologies and smart-city approaches to enhance arboriculture and urban forestry practices (Nitoslawski et al. 2019; Goddard et al. 2021; Prebble et al. 2021). In order for these knowledge gaps to create opportunities instead of barriers for practitioners, more research and dialogue is needed to understand relationships between people, trees, and technology.

Ultimately, arborists and urban forestry practitioners will increasingly be called upon to address complex and multifaceted problems in cities. In the wake of COVID-19, and in the throes of the climate crisis, urban trees and forests are being recognized as crucial components of healthier, more resilient, and more equitable urban ecosystems (Endreny 2018; Derks et al. 2020). As researchers and practitioners in these fields, we will by necessity take on the roles of futures thinkers, strategists, collaborators, and leaders prepared to engage in experimental and adaptive practices—many of which will involve new and emerging data, tools, and methods at our disposal. This will require the expansion of our knowledge base on the opportunities and limitations of implementing these technologies.

OVERVIEW OF THE SPECIAL ISSUE

This special issue of *Arboriculture & Urban Forestry* addresses current knowledge gaps by exploring how the planning, design, management, and use of urban trees, urban forests, and green infrastructure can be integrated into smart-city planning. It includes a range of contributions, geographically and thematically, at the intersection of technology, arboriculture, and urban forestry. Aerial and ground-based remote-sensing tools and techniques constitute a major focus. **Chen et al.** introduce a suite of survey and assessment techniques for roadside trees in Taiwan, integrating high-precision GIS-based instruments, LiDAR, radio frequency identification (RFID), and streetscape imagery. **Lu et al.** use aerial laser scanning approaches to model the provisioning of shade across the city of Vancouver (Canada), highlighting relationships between greenery and urban form across multiple scales. Satellite imagery, coupled with historical aerial photos and maps, were used by **Freeman-Day and Fischer** to track urban forest patches on the Indiana University campus (USA) across a large time series, emphasizing the potential to combine "low-" and "high-tech" tools in urban ecological monitoring. **Pace et al.** compare different field measurement systems, including smartphones with LiDAR capabilities, to quantify tree attributes, illustrating opportunities for small-scale, portable computers to characterize vegetation at finer scales.

Beyond these specific techniques for urban forest monitoring and management, **Staley** discusses the state of knowledge on remote sensing and big data applications for urban forestry, reflecting on scenarios and perspectives for access to and use of modern technology in highly connected cities. **Plitt et al.** examine the importance of digital tools (or "e-tools") for community engagement and stewardship in New York City (USA), finding that hybrid approaches support diverse usership and promote data sharing at scale. **Deak Sjöman et al.** highlight a specific case study in "smartifying" public parks in Gothenburg (Sweden), introducing a criteria-based framework to evaluate the Sustainable Smart Parks initiative. Finally, **Rust and Stoinski** leverage artificial intelligence (AI) to support visual tree risk assessments, suggesting that this system could help standardize assessment practices.

IMPLICATIONS FOR RESEARCH AND PRACTICE

The articles in this issue illustrate the potential for smart and digital technologies to enhance the provisioning of benefits from urban trees and forests, as well as contribute to public engagement and stewardship. Opportunities highlighted in this body of work include automating more laborious and resource-intensive practices, combining different data sets in novel ways to answer complex questions, standardizing data collection and sharing, and enriching understandings of how technology can shape and mediate relationships between people and urban forests. It is entirely possible that newer technologies, along with higher available computing capacity, will in future support more continuous data collection, analysis, and sharing practices that can shed light on urban forest condition, function, uses and benefits, and management needs at increasingly finer scales.

Nevertheless, research on technological applications in arboriculture and urban forestry is still nascent. Future avenues for research could focus on practitioner and policymaker knowledge and perspectives about various technologies, and how they could change the nature of work in the field (Nitoslawski et al. 2021). Horizon scanning and forecasting techniques may help both technology and urban forestry experts understand science-policy-practice gaps and develop clearer pathways for technology innovation and uptake (Parker et al. 2014; Goddard et al. 2021). There is also concern about the environmental impacts of digital technologies, particularly in relation to carbon emissions, energy consumption, and electronic waste (Bieser and Hilty 2018). It will therefore be worthwhile to consider how to mitigate the negative environmental impacts of technology adoption and identify avenues for more sustainable technology solutions (Linkov et al. 2018). Civic engagement and involvement are paramount; with growing interest in volunteered geographic information, citizen science initiatives, and augmented reality, there are ample opportunities to explore how smartphones and mobile applications can inform decisions about urban forest design and access, supported by data on public behaviour and values (Dorward et al. 2017; Foster et al. 2017; Rout et al. 2021).

Although they represent many opportunities for advancing the field, current and emerging technologies, tools, and techniques addressed in this issue are just one part of the urban ecosystem management toolbox. It will be just as critical to consider local and context-specific needs, access to data and computing resources, municipal expertise, and capacity for innovation. It will also be important to thoughtfully consider the varied impacts of technology uptake and to ensure that existing social and economic inequities in cities are not exacerbated. As we look forward and continue to explore technology applications in this field, we should be cautious, purposeful in our actions, and mindful about the civic value being created when engaging in novel, data-driven practices in arboriculture and urban forestry.

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Sophie Nitoslawski
Guest Editor, Arboriculture & Urban Forestry
Department of Forest Resources Management
Faculty of Forestry
University of British Columbia
Vancouver, BC, Canada

Cecil C. Konijnendijk
Editor-in-Chief, Arboriculture & Urban Forestry
Department of Forest Resources Management
Faculty of Forestry
University of British Columbia
Vancouver, BC, Canada

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