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Smart urban forests: An overview of more-than-human and more-than-real urban forest management in Australian cities

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ABSTRACT

These are uncertain times in the Anthropocene, where the health and resilience of all urban inhabitants should be key themes for cities striving for sustainability. To this end, local councils in Australia are applying digital technologies with increasing complexity as components of their urban forest management. This paper applies a more-than-human lens to analyse Australian local council urban forest policies, documents and project information for their inclusion and application of digital technologies. In this scoping review, digital geographies informed data collection to answer questions about the type, use and ownerships of tree data, and more-than-real and 'lively data' concepts were employed to extend their discussion.

Our analysis found that local government policies focused on general urban tree data and canopy percentages and utilised this data to justify and create policy and program parameters. There was a general lack of more-than-human considerations beyond the focus on trees in creating and designing smart urban forests, but it is unclear whether this was due to technical limitations, council desires or other factors. Challenges identified for successful outcomes included balancing priorities, access to resources and information, technological constraints, and community factors such as capacity to engage and cultural values. Digital technologies that facilitate smart urban forests tended to reinforce and re-solidify Western values. However, strengths of current applications are also evident, and we explore how they provide more-than-real possibilities for human-nature relationships to deepen and foster collaborations between disparate groups and entities in urban environments. Greater consideration and acknowledgment of the more-than-human and understanding of the more-than-real in co-creation and co-design of digital technologies and their applications may facilitate more positive outcomes for human and non-human urban inhabitants.

1. Introduction

Shifting climatic, biological, and ecological conditions in cities are prompting new directions for research at the interface of environmental and digital technologies (Phillips & Atchison, 2018). Cities have long been viewed as places of human invention and technological innovation – a narrative that has been particularly prevalent with the emergence of 'sustainable smart cities' agendas (Gabrys, 2014). But there are significant tensions in how smart and green cities are imagined and the constitutive role that digital technologies play in mediating these relations (Bouzguenda, Alalouch, & Fava, 2019; Caprotti, 2018; Gabrys, 2014). Digital technologies are a pervasive feature of everyday life and governments are increasingly using smart cities practices, such as data collection, measurements and management via sensors, 3D imagery and big data, to govern urban forests as part of strategic directions towards becoming more engaged, sustainable cities.

The term 'smart urban forests' refers here to applications of digital technologies for managing different facets of urban forests, such as tree monitors, 3D imagery and citizen science apps. These digital technologies are often situated within urban design and planning as urban greening or green infrastructure. However, Nitoslawski, Galle, Konijnendijk Van Den Bosch, and Steenberg (2019) highlight a gap in the current literature that brings together smart city planning and the ability of urban forests and urban green spaces to 'maximize green benefits for all city dwellers' (para. 1). Escobedo, Giannico, Jim, Sanesi, and Lafortezza (2019) also stress that 'the scarcity of qualitative research approaches in UF [urban forest]-related literature indicates the inadequate understanding of human–environment relations' (2019, p. 4). Similarly, digital geography research reflects growing recognition that due to 'the 4th revolution' (Floridi, 2014), 'the digital turn' (Westera, 2012) and 'platform urbanism' (Barns, 2019), urban human, nature, and technologies' relationships deserve more critical attention, so digital technologies do not solidify unequal, unjust power relationships (Ash, Kitchin, & Leszczynski, 2018; Barns, 2019; Floridi, 2014; McLean, 2020; Nunes & Nisi, 2018). Indeed, scholars encourage research that critiques forms of digitalised urban governance, such as smart urban forests, both in policy and grassroots/community-driven

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efforts, paying close attention to urban situated knowledges and ontological underpinnings (Clarke et al., 2019; Luque-Ayala, 2018; McFarlane & Söderström, 2017).

This paper talks to these limitations and challenges by bringing together smart cities and more-than-human concepts and practices (Choi, 2016). In doing so, it responds to the research question of how are practical efforts that bridge digital and more-than-human domains playing out in the under researched Australian context. The focus of the article is to foster conversations around the co-production and co-design of smart urban forests between humans and more-than-humans. An appreciation of 'lively data' (Lupton, Parisi, Paterson, & Archer, 2017) and reading digital spaces as 'more-than-real' (McLean, 2016; McLean, 2020) is offered to help extend this conversation. These theoretical contributions may help make sense of complex human and more-than-human relations in the context of smart urban forests.

The paper begins by using a critical more-than-human lens to briefly overview smart urban forest literature and identifies the opportunities for expanded Australian research. Next, the paper describes the scoping review used to collect and analyse data and discusses the research scope and associated limitations. We then summarise key findings focusing on the types and uses of data in urban forest policies and programs. The research considers what digital mechanisms are used, who uses these, and discusses these findings in terms of the challenges and strengths of smart urban forests both in Australia and elsewhere. We conclude by reiterating important lessons learned, emphasising the value of expanding and reframing work on smart urban forests.

2. Digitising the more-than-human

2.1. Urban platforms

Theorists such as Barns (2019) and Poell, Nieborg, and van Dijck (2019) have critically engaged with the notion of 'the age of the platform' to explore the role of digital technologies not just as a tool but as a construct that enables the co-creation of new human and more-than-human relationships. However, they also caution that platforms only allow participants to change and expand the data collected, the uses of the data and even the platform functions and operations themselves, only so far as it is within the parameters to do so set by the original platform creators. As the use of platforms takes hold in an industry, the primary or more successful platform becomes the standard by which future platforms build on, such as the Uber platform in the shared transport industry (Barns, 2019). Digitisation often proceeds via platforms, so it is prescient to keep in mind these critiques of top-down intervention and the shaping of certain affordances that emerge with digital technologies.

Within the context of digitising more-than-human environments in Australia, there is a large focus on the smart urban forest of Melbourne, in particular its mapping and email functions (discussed further in the Australian Context section below), and more generally an increase in the usage of the i-Tree software originally deployed in the first Australian urban forest benchmarking report (Jacobs, Mikhailovich, & Delaney, 2014). The i-Tree Suite programs allow users to input data which the programs then convert to desired values. For example, i-Tree Eco converts general tree data into approximate ecosystem services per annum and i-Tree Canopy uses the cover type of random sample points to determine what percentage of an area is canopy or other surface types (i-Tree, n.d.). The use of programs such as i-Tree Eco and i-Tree Canopy is gaining traction globally as governments and organisations try and grapple with both valuing and communicating the concept of ecosystems services – seen as the measurable environmental benefits of individual trees and forests to humans.

As Barns (2019) highlights, with novel urban platform applications there comes a prerogative for creators and users to think about these platforms and their influence, both as actors and as sites for diverse socio-spatial encounters "beyond ontologies of control, transaction and appropriation" (p. 9). In recognizing the importance of understanding the basis upon which platforms are created and the parameters that allow participation, this paper attempts to explore what kind of data is generated, what the data represents, who has access to this data and what this data is used for in regards to smart urban forests. By doing so, we identify what agencies and power relations play out (and point to those that might play out in future digitisation of more-than-human spaces) within urban platform ecosystems. The 'more-than-human' concept is applied in this paper to explore 'how the social, cultural and political are forged in relation to a retinue of nonhuman potentials and forces' (Barua, 2018, para. 1) in smart cities. More-than-human research helps highlight the agency of non-humans in attempts to decentre human perspectives and exceptionalism that is a feature of Western, Enlightenment and modernist thinking (Houston, Hillier, MacCallum, Steele, & Byrne, 2018). In their book on more-than-human participatory research, Bastian, Jones, Moore, and Roe (2017) state that the more-than-human research agenda 'has sought – in one way or another – to take nonhuman life, and the entanglements of human/nonhuman life, seriously and to thus step away from the modernist dismissal of nature and nonhumans as anything but resources' (p. 2).

2.2. More-than-human in the urban

In recent years, other disciplines have also sought to expand knowledges of the ecological relationships within cities. For instance, urban ecological science transitioned from thinking about ecologies *in* cities as pockets of non-urban habitats, to ecologies *of* cities encompassing all natural and built environments as one social-ecological system. Further, ecologies *for* cities include the ecologies in and of, and knowledges generated by the researcher, that may promote urban sustainability (Pickett et al., 2016).

However, while there is a burgeoning literature on the subject, urban politics and planning has 'yet to embrace the urban as a multispecies, multi-thing reality in which nonhumans are active participants alongside humans in shaping cities and places' (Quinn, 2020, p. 1). More-than-human urban research has sought to disrupt the human-centric exceptionalism of urban life – carving spaces for the recognition of and attunement to the agencies of nonhumans in co-producing the urban (Houston et al., 2018; Steele, Wiesel, & Maller, 2019), and more specifically, what that means for future research if planners recognise urban forests as becoming-urban (Jones & Instone, 2016). These realities explore myriad of interconnections between living and non-living entities and worlds that are rendered visible or invisible – from the microbes that have brought our cities to a stand-still during the Covid-19 pandemic to the smoke from the devastating 2019–2020 Australian bushfires that infiltrated lungs and buildings.

Quinn (2020) in particular, draws attention to the multiple ways in which "other-than-human entities" assemble and configure heterogenous urban spaces and relations. Quinn examines more-than-human entanglements in the Mangles Bay Marina in Perth, Western Australia and explores the enrolment of lively nonhumans such as seagrass as well as technical artifacts in the proposed marina development. In a different vein, Houston (2019) highlights how endangered Carnaby's Black Cockatoos (also in Perth) exert lively agencies through their foraging, roosting and flight ways through the city. Such lively black cockatoo inhabitations are entangled with other urban productions of space – including planning instruments, biodiversity offsetting policies, urban bushland protection, citizen science and community gardening. In Sydney, Kirksey et al., 2018document the collaborative wing-tags program – where yellow wing tags were attached to Sulphur Crested Cockatoos along with a smartphone app and a Facebook page have allowed scientists to track their movements and where human and nonhuman participants shared social exchanges and forged new modes of conviviality.

Human and non-human processes and entanglements extend into worlds long considered in Western culture to be 'inanimate'. For example, Waitt (2008) analyses how surfing involves dynamic nonhuman forces such as weather, water, and rocks in relation to discourses of sex, race and gender. In critical feminist research, Neimanis and Hamilton (2018) engage with weathering as a force that can help us understand how bodies, places and the weather are interrelated in climate change affected worlds. Melo Zurita (2020) explores the political materiality of urban undergrounds as a form of 'terra nullius', the erasing of the geodiversity of Indigenous underground worlds in the name of urban development and extraction. Our point is that more-than-human thinking entails far more than Western categorization of animate, inanimate, lively, dead. It is an approach that seeks to understand processes by which entities and objects come into relation with certain consequences for which forms of life are contained and which forms of life can flourish, and under what political and material conditions.

2.3. Urban more-than-human agencies

When it comes to thinking about the role of digital technologies and platforms within cities – the more-than-human is somewhat fraught. For example, in feminist new materialist research, Lupton and Maslen (2018) study wearable technologies and propose that 'Digital technologies are considered to offer more-than-human capacities for recording and remembering information that can readily be retrieved and responded to at a later time' (p. 197). While this may be a useful extension of more-than-human thinking, there may also be a tension in this proposition. The agency of digital technologies is nearly always shaped by humans – they are largely produced by and for human purposes. It is worth noting here that there are efforts underway to design autonomous processes which attempt to reduce human influences on more-than-humans, while also increasing levels of human management with digital interventions (Cantrell, Martin, & Ellis, 2017; Gulsrud et al., 2018). Nevertheless, these digital technologies that have a component of autonomy are initially conceptualised and supported by humans, so the source of agency still includes human activity.

The more-than-human might be better understood as a term that is relevant to natural entities, as problematic as such a category can be. Instead, we could refer to digital technologies as more-than-real in how they facilitate different relations between humans and nonhumans (McLean, 2020). If we consider the digital as more-than-real, the theoretical contributions of more-than-human research can be built upon and adapted for non-living, technological agents. The more-than-real idea highlights the generative and destructive potential of digital technologies. By critiquing the not-realing that often comes with thinking of digital spaces, the more-than-real offers a way to bring together thinking on the more-than-human with digital technological perspectives (McLean, 2020; McLean, Maalsen, & Prebble, 2019). It also continues the new materialist focus of Lupton (2019) and highlights the ramifications of misreading the digital as immaterial and other than real. Pointedly, more-than-human geographers are beginning to appreciate plants as 'co-producers and/or subjects with their own differentiated agencies', where previously 'the majority of attention of more-than-human geographies has fallen on non-humans other than plants' (Phillips & Atchison, 2018, p. 4). Certainly, Atchison and Head (2017) argue for 'more humble recognition of plants' diverse capacities and ways of being' (p. 13). Considering these more-than-human plant capabilities and urban forest ecosystems entangled within human and technological constructs poses a challenge for urban planning and yet urban planners are not shying away from exploring these concepts. Nitoslawski and Galle (2019) propose that just as "people in cities connect with trees…it is now time to consider how trees might connect – literally – to people" (para, 1).

The agency of plants is enhanced by digital technologies in some instances, suggesting that the more-than-real can create unexpected possibilities that are generative. Although there have been movements that acknowledge nature's agency in governance mechanisms such as rights granted to rivers in New Zealand and India and specifically tree agency in rights granted to the Amazon Forest (Macfarlane 2019), Konijnendijk van den Bosch (2016) suggests increased consideration of tree agency in urban forest governance, advocating for "recognising the crucial roles trees play in creating place – and ultimately also in creating cities where the human and non-human go hand in hand" (p. 185).

Using a more-than-human lens, Cooke, Landau-Ward, and Rickards (2019) also identify many areas in which urban greening policies and practices that are restricted by Western and settler socio-cultural concepts flow directly from the idea of property rights, such as ideas including 'public', 'common' areas and 'private' property, often bestowing unequal power to private property owners. These limitations prevent policies and practices from being attuned to or considering more-than-human lifeworlds, such as spatial differences, including issues of access to water, nutrients, soil microbes, fungi and kin (limited by property boundaries) for urban trees. By bringing into conversation the literatures on geographies of platforms and smart cities with the more-than-human, this paper offers a critical engagement with research that is looking at the agency of non-humans in urban contexts. The more-than-real/human relations that are glimpsed in this conversation include the lively entwining of humans and nonhumans.

3. Methods

3.1. Scoping review

This paper adds to more-than-human research through its scoping review of literature and Australian urban forest strategies, policies and programs, using a comprehensive textual analysis of documents accessed online. As Kullman (2013) highlights, using a geographic lens such as the more-than-human supports the process of knowledge production around urban governance. Therefore, a geographic scoping review underpinned by digital and more-than-human geographies was executed via a textual analysis of local government policies and other online documents related to urban forests management and projects (such as collaborative projects for data collection or decision-making). This is comparable to other urban forest research (Konijnendijk, 2008; Lawrence, 2006; Jones & Instone, 2016) which has used similar methods as an appropriate analysis across several actors and spaces (Winchester & Rofe, 2010). The primary focus of data collection was Local Government Areas (LGAs) who are actively designing and implementing urban forest policies, strategies and programs, including digital technologies, to manage their urban forests. In Australia, LGAs are an administrative division of a state or territory and manage parks, waste and recycling, environmental protections, local roads, some transport and facilitate services such as public libraries.

3.2. Search criteria and scope

A literature search was performed online in multiple databases using terms such as 'urban forest', 'urban forest planning', 'smart urban forest' and 'digital urban forest' and although this review focus is the Australian context, the literature was not limited to material discussing Australia. Table 1 presents the full list of search terms.

The second component of the data gathering for this paper was a review of urban forest policies, strategies and programs. This scoping review was limited to Australian examples and included only those that could be found online, using terms such as Australian urban: forest, governance, policy. This geographic limitation was chosen to allow for a deep and

Table 1
Terms used for literature review search (categorised here for clarity of presentation).

Digital	Urban	Smart
Digital Urban Forest Governance	Urban forest governance online	Smart city/ies urban forest governance
Digital Urban Forest Governance Australia	Urban forest citizen engagement	Smart city/ies urban forest
Digital Citizen Engagement Australia	New Media urban forest	Smart city/ies urban forest citizen engagement
Digital Citizen Engagement Urban Forest	New Media Australia urban forest	Smart city/ies urban forest Australia citizen engagement
Digital Citizen Engagement Urban Forest Australia		

Table 2
Terms used to review smart urban forest policy in Australia.

Citizen science	Citizen engagement	Engagement	Mapping	Virtual
Online	Internet	Digital	Interactive	Immersive
Community	Community involvement	Technology	Technologies	Software
Hardware	Computer	Data	App	i-Tree

place-specific analysis, and with the recognition of previous research of urban forest management elsewhere in Canada (Duinker et al., 2015; Duinker, Steenberg, Ordóñez, Cushing, & Perfitt, 2014; Kowalski & Conway, 2019), Scotland (van der Jagt & Lawrence 2019), the US (Maco & Mcpherson, 2002; Nowak et al., 2010), Turkey (Atmis, 2016), China (Yao et al. 2019), Korea (Parka & Younb, 2013), Niger (Hungerford & Moussa, 2017), England (Monteiro, Handley & Doick 2019) and Europe (Lawrence, Johnston, Konijnendijk van den Bosch, & De Vreese, 2011).

Documents were not limited to using the term 'urban forest' but also included LGA, other government and political party policies and documents produced by groups or collaborations that linked to, or specified links to, the urban forest such as tree management plans (where no urban forest strategy was found), nature in the city, regional policies/plans and other applicable documents and information from websites (such as Cool Streets and Which Plant Where). Only programs or collaborative projects that focused on novel application of digital technologies were included. Table 2 presents all search terms for the policy review.

Policies were searched for content that connected to digital/smart urban forests using a list of search terms, however policies were included for analysis even if they had little to no explicit mention of digital technologies but had digital data management systems and the literature was reviewed to answer the following questions: What kind of data is generated from smart urban forests and can be accessed/is being accessed? What does the data represent and how is this data being used? Understanding how data is collected and utilised provided insight into epistemologies of design and implementation of digital technologies.

In developing an expanded understanding of data management and the role of digital technologies, we consider all documents that could be located digitally (a total of sixty-six) on the topic of smart urban forests in Australia and, while several draft policies from local government were available, future research may look to surveying councils for information on upcoming or planned urban forest policies to capture a more comprehensive suite of policies and programs.

4. Review results

The data mainly represented two things: tree biology and human-derived tree values and these were presented within boundaries (geographic such as suburb; demographic, such as tree planting activities targeting areas of vulnerable peoples; and land use, such as parks, street, public, private). Several documents attributed values to trees and/or the urban forest based on environmental benefits provided by trees to the community. In some cases, these were then used to determine monetary values of these 'community assets'. Tree monetary values were also calculated in some documents based on aesthetics, property values and social benefits (singular or in combination). Values were conceptualised within actions to be taken, processes and plans, such as the determination of trees with lower human value to be removed or receive less protections.

General tree data is highly used in the reviewed documents, and urban canopy was the most frequently referenced within this field. General tree data included tree family, species and genus, size (height and canopy width), location and situation on land type (park, street etc), if trees were significant or regulated, and the age and condition. This general data was then used to provide measurements, values and make connections between data points. For instance, twenty documents set targets or action plans for increasing bio-or tree diversity to make the urban forest more resilient and sustainable, such as the City of Sydney's and City of Melbourne's (CoM's) targets for family, genus, and species (City of Sydney, 2013; CoM, 2017). Location data was also used to highlight areas that could be targeted for more immediate actions, such as those with many vacant tree spaces or those with trees in poor condition or of advanced age. Location data mixed with socio-economic demographics of people in an area, often using a vulnerability index, indicated those areas where positive socio-economic outcomes could be enhanced through tree planting.

Canopy data was particularly important, with almost 60% of the documents referring to canopy as the main measure of or target for urban forests. Canopy values, as a percentage of land, were used to guide planning and design of actions to achieve overall urban forest goals, such as maintaining and/or increasing overall canopy cover, as well as more specific canopy cover targets in specific areas (e.g. suburbs or land types).

Most documents communicated temperature, heat vulnerability and/or urban heat island (UHI) data. Less frequently gathered data included water stress and water design, climate change indicators, biodiversity, fire risks and community values and attitudes. Community engagement data included emails, submissions via 'Have your say' online portals, statements from surveys, working groups, engagement events and recorded activities such as occurrences of vandalism and other types of harm/removal of trees.

The three main types of digital technologies in the documents were the i-Tree Suite of programs (i-Tree Canopy and occasionally i-Tree Eco), digital aerial photography/LiDAR (light detection and ranging – a remote sensing method) and tree inventory databases and these were often combined and analysed using GIS. The iTree programs take raw tree data and turn it into more useful values in relation to a specified area – for example, turning height and width of trees into a canopy cover percentage while LiDAR technologies use light detection and ranging capabilities to produce 3D images of landscapes. Less common were social media (such as YouTube videos), interactive online mapping/forecast tools, online surveys, websites (disseminating information, online contact and 'have your say' forms, Greater Sydney dashboard, soundscape), online guides (such as tree selection tools and calculators/valuations), asset management databases, apps (such as the 'My Favourite Tree' app), online registers of significant trees, ecological footprint and citizen data collection (via digital technologies or incorporated into existing ones).

Tree and urban forest data were mostly available to council and participating organisations (such as consultants, arborists and other contractors or research/project collaborators). Collaborating organisations included the CSIRO, consultants, 202,020 Vision (now Greener Spaces for Greener Places), universities and service providers. Several documents notably referenced community groups and volunteers and nine identified Indigenous communities as important in collecting data and designing policies. CoM provided a high volume of data to its citizens and several other LGAs provided various sets of open data, mostly mapping and tree inventory. Policies mainly promulgated councils as information gate keepers with several projects requiring membership or registration to access information and the knowledge/data that was made freely available was often to facilitate community engagement and therefore had a strong focus on promoting trees as assets by stating urban forest benefits.

Data was overwhelmingly used as key indicators and justifications for strategies and actions to manage urban smart forests. For example, in discussing the UHI effect, the City of Yarra (2017) established that 'an urban forest is an efficient and cost-effective mechanism in mitigating the urban heat island effect' (p. 7) and further mapped vulnerable communities to prioritise resource allocation. See Table 3 for summarised data use.

Interestingly, those LGAs with projects that incorporate digital technologies in urban forest governance did not discuss these projects within their urban forest strategies in significant detail. It was therefore challenging to determine exactly what data was used and how platforms had been designed. However, analysis of websites and project information brochures produced the following data (Table 4).

5. Discussion

Smart urban forest approaches are being incorporated in Australian urban forest policies to justify, enhance and influence goals and actions

Table 3
Summary of data collected and used in reviewed Australia urban forest strategies and policies.

Data Type	Component of Policies	Used For	Example
General Tree Information	Planting schedules, removal/pruning, DAs	Tree species and location selection, assessment	The City of Armadale Urban Forest Strategy mandates specific tree species per area to maintain landscape character (City of Armadale, 2014)
Canopy	Policy development, planting schedules, DAs Collaborations,	Targets, Actions Plans and assessments, tracking changes, benchmarking	One City of Banyule goal is to increase canopy cover in available open space as identified through I-Tree assessment (City of Banyule, 2019)
Climate (UHI, temp)	Development, justification	Targets, Action Plans	CoM principle: Reduce the UHI effect: a detailed CoM study recommended increases in canopy cover to mitigate heat retention in the city (City of Melbourne, 2017).
Ecosystem Services	Community Engagement, tree management/planning	Citizen awareness, tree selection, laws	City of Whitehorse prosecute tree vandalism to recover costs, including tree ecosystem services value (City of Whitehorse, 2018)
Valuation	DAs, removal/pruning requests, allocation of resources	Assessments	City of Burnside created their own valuation system which they use to make decisions about trees in development applications (City of Burnside, 2014).
Community Values	Policy development, significant tree register, project.	Design of policies, projects and community engagement	Town of Victoria Park held interviews, surveys, workshops and public forums that contributed to policy development (Urban Forest Strategy Working Group, 2018)
Demographics	Development	Planting and resource allocation	Greater Shepparton mapped demographics such as age and socio-economic status to ascertain priority plantings (Greater Shepparton, 2017).
Land Use	Policy development and development applications	Design of policies, especially targets, landscape and community benefits	City of Woollongong measured canopy cover percentage per land use (i.e. 11.5% on private land) in order to develop a strategic framework to protect and manage the whole urban forest (City of Woollongong, 2017).

Table 4
A summary of analysed Australian smart urban forest programs.

Program	Collaborators	Digital Technolog(ies)	Purpose
Coolstreets	Community, Blacktown Council, Gallagher Studio, CRED Consulting	3D imagery, streetscape forecast modelling	Citizens take ownership of tree choice
Urban Forest Interactive	City of Burnside	Interactive Website (tree location, general information and ecosystem services)	Engage citizens (understand urban forest, vacant tree spots and invite citizens to become 'Urban Foresters')
Urban Forest Visual (City of Melbourne, 2016)	CoM	Interactive Map (tree location, general info and contact via email)	Engage citizens (tree planting and communication)
Cooling and Greening Interactive Mapshare Tool	CoM	Interactive Map (vegetation cover and overlays of previous and present heating/heat vulnerability)	Engage citizens and justify/support CoM policies and actions.
Open Tree Data Platforms (incl. data.gov.au tree datasets)	Councils with and without (e.g. Ryde, Southern Grampians) urban forest strategies and citizens	Tree locations and general info (database and map)	Council strategy and actions plans, citizen planting decisions.
PlantCities	CoM, Academics, Government, Artists, Citizens, Trees	Website Soundscape with pictures	Engage citizens further human-tree relationships, care for urban forest.
Tree Monitors	Academics, Industry, Citizens	Tree monitors (water/stress) and proposed App	Better urban forest management, citizen engagement
Which Plant Where Interactive Tool (Which plant where, 2020)	Academics, Citizens, Government, Industry, Community Groups	Online interactive tool	Better urban forest management (focus on long-term planning, appropriate tree planting)

and in some projects to facilitate stakeholder engagement towards collaborative goals. This discussion builds on Gabrys' (2020) exploration of forest digitalisation, which highlights how "forests are *becoming social-political technologies* for addressing enviornmental change" (emphasis in original, n.p.) and potentially influencing environmental engagement and governance. By reflecting on the agencies of humans, nature and more-than-humans within this context, contentions between digital technologies, human-nature relationships and sustainability may be reconsidered. As our findings highlight, there are many positive and interesting ideas, concepts and projects that incorporate digital technologies in urban forest management being supported by smart urban forest strategies and tree management policies in Australian cities. Challenges and strengths were both highlighted in the policies themselves and further became apparent in applying literature to understand review findings and here we discuss the most prominent from the analysis.

5.1. Challenges

5.1.1. Digital harm and categorization

Our smart urban forest review indicates that tree health is an overarching challenge on public and private land. This is exacerbated by issues with the capacity for data to be up-to-date, real-time and effectively used in management. Vandalism is mentioned as a contributing factor to tree health in several policies and this may be further facilitated as tree location data is made available online (Verma, 2016). This is an example of 'digital harm' (Lupton, 2019): harm that befalls an entity when their data is used against them. Digital harm is a complex issue as, similarly to human data, the use of certain tree data metrics can 'privilege some individuals…over others' (Lupton, 2019, p. 10) Certain trees are therefore harmed (pruned or removed) due to their digitalised data such as their species, position in relation to boundaries, expected or estimated 'useful life', ecosystem services or monetary values. For instance, trees with higher monetary value (such as those with wider canopy measurements or with longer useful lifetime left) receive greater protections and allocation of resources.

Our research indicates that digital technologies are critical in council workers decisions to plant which tree and where; a form of data-driven surveillance is at play in smart urban forests. Lupton (2019) suggests that this kind of 'dataveillance' means that entities, in this case, trees, have no ownership or control of their data and therefore may not be instrumental in decision making. Including more-than-human considerations into the creation of digital technologies might mean that as trees dynamically engage with their environments, data points may change, influencing actions of other entities within the system, for instance, a self-watering system or triggering maintenance due to mycelial network damage. It is challenging to imagine how much control over data and broader decision-making trees might entertain in the future within anthropogenic governance systems that still lack comprehensive *human* data regulations (Lupton, 2019).

5.1.2. Neoliberal digital design

These governance systems also struggled to account for local, diverse, and more-than-human epistemologies in digital technologies within Western, neoliberal designs. Büscher (2016) puts forward the concept of Nature 2.0 – the engagement of humans and nature through web applications such as social media platforms and cautions that while digital technologies allow the 'reimagining of nature online' (p. 738) there must be consideration of the neoliberal capitalist paradigm as the basis of their design that promotes and obfuscates the commodification of nature. Furthermore, Jones and Instone (2016) and Cooke (2020) highlight the strong focus on quantitative data collection and commodification of Australia's urban forest to date as a product of historical epistemologies. While there is emerging evidence of qualitative data analysis, particularly via platforms, our findings reflect these critiques as urban forests were reduced to numerical values within digital mapping, databases, and policies. Policies referred to co-ordinates of geographic locations and urban forest/tree measurements, ecosystem services, percentage of areas/canopy and with referenced changes, such as number of trees or percentage of areas and further, these numerical values were often evaluated in monetary terms. Tree management policies often promoted the planting of certain species and protection of certain trees over others, based on the utility of these trees to humans.

As Barns (2019) speculates, this digitisation without deeper considerations "may inadvertently render the space of the urban as a subsumed domain of smart, algorithmically governed infrastructures" (p. 9). The shift to market-led digital urban forest governance therefore requires extra attention as market-based values may not align with social, environmental and more-than-human values (Konijnendijk van den Bosch, 2016). While there can be investment issues when forest governance is influenced by non-market-led agendas (Matsler, 2019) one risk of positioning trees as green infrastructure is that anthropocentric valuation in urban settings is elevated at the expense of more-than-human agencies.

Our findings support the current literature that suggests the design and use of digital geographies in urban governance encapsulates and solidifies Western knowledges and upholds neoliberal values as the product of digitally-mediated human agencies (Barns, 2019; Luque-Ayala, 2018; Rose, 2017). This policy analysis supports the critique that utilizing digital technologies within a neoliberal planning framework, reinforces current power dynamics and is limited by existing structures (Giest & Ng, 2018) so that social, cultural, political and multi-species inequalities are recreated and solidified when designed and employed by planning institutions (Lupton, 2019; Luque-Ayala, 2018; Rose, 2017). For instance, Clarke et al. (2019) discuss the digital design challenge of limited linear human timescales, such as political and research funding periods and their current hierarchies with respect to more-than-human timescales, such as climate change or the age of tree biomes.

5.1.3. Lacking more-than-humans in digital technologies

Application of a more-than-humans lens highlights significant challenges for digital technologies to effectively capture and translate data for tree ecosystems and of tree capabilities. The liveliness of urban forests is somewhat collapsed in data gathering that focuses on height and canopy cover while overlooking aspects such as temporal differences, diverging boundaries (e.g. especially in terms of both LGAs and distance to other trees and roots, water, fungi), family members or kin and other species and capabilities such as finding water, seasonal responses and plant learning. Just as community groups working in dense clusters have little diversity and sharing of information to promote innovation and resilience, tree clusters are also isolated – from other trees, plants and importantly hidden or unseen factors such as fungi and pollinators, which are very important to trees but not visible in traditional digital technologies such as 3D imaging, aerial photography, mapping and more.

Our identification of limited or absent plant capabilities data tends to point to a possible lack of capacity for digital technologies designs to incorporate the 'huge amount of research that has shown nonhumans are capable of a much wider range of cognitive, emotional and symbolic behaviours than they have traditionally been given credit for in Western cultures' (Bastian et al., 2017, p. 7). Examples of such work include research on mimosa plants that may learn to distinguish between types of threats (Gagliano, Renton, Depczynski, & Mancuso, 2014) or learn to forget a response in order to save energy (Crisp, Ganguly, Eichten, Borevitz, & Pogson, 2016), how pea plants learn to associate different stimuli and react to them (Gagliano, Vyazovskiy, Borbély, Grimonprez, & Depczynski, 2016) as well as evidence for sound-evoked physiological reactions in plants (Jung, Kim, Kim, Jeong, & Ryu, 2018).

5.2. Strengths

5.2.1. Possibilities for human-nature relationships to deepen

Perhaps the most significant strength of incorporating digital technologies in urban forest management is the possibilities that digital technologies afford for human-nature relationships to be created, supported and enhanced. Stakeholder engagement was integral to policies, and many not only disseminated information about policies, programs and tree/forest issues to increase engagement and awareness, but actively sought out online communication from citizens and the wider community about their attitudes towards, and experiences with, the urban forest. Use of the 'YourSay'[1] government stakeholder consultation platform accounted for a considerable civic response to draft urban forest and related policies, prompting stakeholders to consider their own relationships with the urban forest and how policies might affect these and associated everyday activities.

Platforms were also widely used to enhance understandings of the role of urban forests and in some cases, specific trees, within broader and local ecosystems. They also allowed expression of values and perceptions of urban forests and trees that went beyond monetary or market values, such as arguing for greater protection for trees with local historical value, to provide environmental benefits and habitats. Allowing the inclusion of local, situated knowledges through digital technologies is important in understanding the context, and facilitating deepening of human-nature relationships. These forms of engagement afford the capacity to influence amendments so that the final policies enacted might be co-created by citizens, government and urban forests. Indeed, Nitoslawski and Galle (2019) suggest the current focus of technologies is the use of open data and citizen engagement and that there is the "potential of digital infrastructure to enhance forest benefits and the facilitation of citizen stewardship and empowerment in green space planning" (para. 2).

Interactive and online maps with tree data can help users to relate to data presented in the local context by appealing to their sense of place through experiences of trees within that place. For example, novel platforms, such as CoM's Urban Forest Visual and City of Burnside's Urban Forest Interactive allow users to obtain information about specific trees, including their location and ecological services. This data can help connect human users with more-than-human affects establishing more direct yet complex understandings and relationships. It is clear from the host of CoM's urban forest (and related) policies that the CoM places a key emphasis on tree-human relationships and virtual and physical experiences as a unified relationship that is a critical component in successful urban forest management (Phillips & Atchison, 2018, CoM, 2012). In designing their Urban Forest Visual, the ability for email communications to specific trees was seen as a method for more effective tree (resource) management, with CoM councillor Arron Wood commenting that they envisioned these

[1] 'YourSay' is a lcoal government consultation hub designed for councils to receive responses to draft plans/policies. It allows documents to be shared and timeframes with consultation and policy development activities and updates to be communicated. They are separate for each Australian state (https://yoursay.sa.gov.au/).

communications would be citizens describing situations the trees were in and their effects, such as if they needed pruning or were vandalised (Tan, 2015).

Similarly, to other novel digital applications (McDonald, Stowell, & Bryan-Kinns, 2018; Nunes & Nisi, 2018; Verma, 2016; Watson, 2011), CoM were surprised by the different engagements that they saw taking place on the platform following its launch. Although one-sided, people from Melbourne and the wider community, including internationally, often use the email function accessed via the interactive map to communicate more personally with the trees by writing to a specific trees' email address, about fond shared memories and expressing deep appreciation (Tan, 2015). The website Plantcities.com showcases some of these 'love letters' as a Soundscape of several prominent trees which includes readings of emails specific to each tree and an artist's impression of how the trees might respond (Plantcities.com, 2019). Phillips and Atchison (2018) analysed these personal human-tree emails and found that grief and gratitude were overwhelmingly expressed in these communications. They advocate for continued use of stories of human-tree engagement 'to highlight the import of everyday relations with trees in an effort to promote or manage their presence in cities' (Phillips & Atchison, 2018, p. 2). In affording the expression of intimate feelings and experiences, the platform nurtures human-nature relationships, which is important both for humans and urban forests as individuals that exhibit stronger connections to nature have been found to be happier, healthier and display environmentally sustainable behaviours (Nilsson et al., 2011). These affective forces of tree-human-digital interaction are a surprising and welcome aspect of more-than-real geographies.

5.2.2. Fosters collaborations

Digital technologies were found to not only increase knowledges and deepen relationships but also to expand capacities and scope for policies and projects through facilitating collaborations. Collaborations are evident in several projects that incorporate elements of co-design and co-creation into their smart urban forests. The Blacktown Cool Streets project involves Blacktown Council, Trees, citizens and Gallagher Studio (a software company)[2] and Which Plant Where involves a variety of universities, local councils, government bodies, citizens, industry, business and technology companies. This is part of an emerging global trend towards mixed collaborations (public, private, industry, more-than-human). Indeed, Badach and Dymnicka (2017) challenge governance to focus on networks 'rather than hierarchical relations' and instead be 'reinforced by diversified resources, actors and their knowledge and experience' (p. 4).

Nunes and Nisi (2018) highlight several projects that have successfully delivered digital technologies that have incorporated non-humans as participants in their co-design, supporting the notion that 'we need new opportunities to use technology to raise awareness…and hence contribute to leverage the co-creation of environmentally and socially just post-anthropocentric cities' (p. 4). Jones (2018) advocates that 'this kind of endeavour would be a major step in terms of making urban space more just, more co-liveable, more eco-flourishing for humans and non-humans' (emphasis in original, p. 2).

Houston et al. (2018) further encourage the use of two concepts in planning theory that take into consideration the multispecies entanglements that support urban flourishing: connectivity (de-centring the human and instead focusing on connections in ecological terms) and becoming-world (being open to the possible outcomes of relational processes between human and all non-human, living and non-living). By placing the human into a relational sense of being and challenging traditional dualistic urban research of separate natural and built environments, human-centric ontologies and epistemologies may begin to be disrupted (Hinchliffe & Whatmore, 2006; Pearce, Davison, & Kirkpatrick, 2015; Rose, 2012; Whatmore, 2002). Crucially, in order to respect and incorporate human-nature relationships in planning through digital technologies we must endeavour to urgently rethink knowledges of cities and technologies and abandon human-centric design and planning in favour of more-than-human approaches that acknowledge non-human actors to successfully co-create sustainable more-than-human cities (Clarke et al., 2019; Floridi, 2014; Latour, 1993; Maller, 2018; Nunes & Nisi, 2018).

While these human, more-than-human and more-than-real relations are constructed in what many see as anthro- and techno-centric, Verma (2016) and Mallar (2018) argue that non-humans express their own agency in more-than-human ways and thus create more-than-real 'lively materialities' (Lupton, 2019). For instance, the City of Burnside Urban Forest Interactive uses i-Tree Eco software so citizens can see ecological services statistics for individual trees, such as annual carbon sequestration (City of Burnside, 2017) which are approximate values for real and material effects each tree produces and that act upon other actors within the ecological system. Dynamically, the input of new data changes these values based on the changes experienced by the tree (such as growth, lifecycle stage etc) and therefore communicates how these changes relate to other parameters within the local ecosystem, such as the benefits enjoyed by citizens.

Reading smart urban forests as more-than-real highlights the liveliness of their data due to three attributes: the data is based upon living things; forests are dynamic and fluid and the data influences not only digital technologies but the actions of users themselves (Lupton, 2017). Lupton (2019) uses feminist new materialism to reflect on lively data and we could draw on this approach to emphasise that these data assemblages conjugate human and more-than-human relational agencies, producing vital materialisms that generate *real* capacities for creating, impelling and shaping human action (see also Heitlinger, Bryan-Kinns & Comber, 2018). The i-tree eco platform is a prominent technology used in these respects: both shaping policies and influencing human actions as tree data represents tree features and changes to the trees, collected and manipulated by humans and technologies. While Lupton (2019) focuses heavily on human-data assemblages, she also explores how Haraway's more-than-human approach examines the messiness of human, other living and non-living entities and highlights how agential capacities 'empower and vitalize actors in the assemblage; but can also expose them to vulnerabilities and harms' (Lupton, 2019, p. 469). The CoM Urban Forest Visual is an example of the more-than-realing of the more-than-human, with digital technologies avowing trees agencies (changing tree data represents changes in the trees themselves) that invoke emotional responses (via email) that can vitalise humans to create new policies and actions. As outlined, these policies are significantly skewed to benefit humans so understanding these messy assemblages as being more-than-real, underscores the importance of providing opportunities for co-creation and co-design to support positive outcomes for all.

6. Conclusions

The application of digital technologies in cities is expanding at a rapid pace and our research suggests that to maximize the potential for positive outcomes for all city inhabitants, consideration should be given to how these inhabitants can have input in their creation and design. Smart urban forest approaches are being incorporated in Australian urban forest policies to justify, enhance, and influence goals and actions and in some projects to facilitate stakeholder engagement towards collaborative goals. By reflecting on the agencies of humans, nature and more-than-humans within this context, contentions between digital technologies, human-nature relationships and sustainability may be reconsidered from sustainable consumption 'towards a collective, participatory and holistic understanding that considers social and environmental justice within multispecies contemporary urban life' (Heitlinger & Comber, 2018, p. 10). It may allow us to find ways in which we 'find another relationship to nature besides reification, possession, appropriation, and nostalgia' (Haraway, 2008, p. 158) as evidenced by the CoM Urban Forest Visual human-tree email communications.

[2] Cool Streets involves community participation in making decisions about street tree planting using the Cool Streets Method developed by Gallagher Studio that allows community members to see designs involving long-term projections of planting certain trees, including shading which is linked to cooler streets and lower energy bills.

Although we highlight here several new opportunities for enhancing management, citizen engagement and understandings of urban forests, we also caution that current applications of digital technologies to urban forest management glaringly re-solidifies Western dualisms and capitalist ideologies. Online websites, databases and platforms relied heavily on numerical values associated with trees and more broadly with urban forests, especially canopy cover, expressed as value for humans. Further exploration of dynamic human-nature-techno relationships and expansion of more-than-human knowledges of the city is needed to reconceptualize the design and use of digital technologies, including how they create more-than-real, vital materialities and impel human actions. To overcome challenges, such as complex and dynamic data collection, our findings suggest that more-than-human considerations be included in the initial planning and design stages of technologies. This may facilitate and allow attention to 'lively' and 'enchanting' vitalities (Lupton, 2019), capable of producing positive outcomes for human, more-than-human and their relationships.

Further research could draw on the research offered here by examining the lived experiences of those engaged in urban smart forests, including community members, managers, digital technicians and the forests themselves. It is worth noting that the explicit identification and protection of forests in cities is a relatively new phenomenon and adding to this repositioning with a layer of 'smart' technology produces interesting opportunities to better understand interactions of more-than-real and more-than-human agents. Emerging questions include how to avoid re-centring the human in these innovations and how to increase the diversity of voices and actors when expanding governance of urban environments.

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Declaration of interests

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