GREEN INFRASTRUCTURE IN SOUTH AFRICAN CITIES

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Urban green infrastructure plays a vital role in providing ecosystem services to cities. These services benefit urban residents directly but are also key to cities' climate change adaptation and mitigation strategies given the increase of climate-related risks within cities. It is critical for local governments to consider green infrastructure solutions in development and climate adaptation strategies. This paper examines the barriers and enablers of the implementation of green infrastructure, specifically focusing on the issue of temperature regulation in South African cities. Drawing on published literature and case studies from the City of Cape Town, the City of Johannesburg and Manguang, the paper aims to help fill an important policy and practice gap and provide direction for cities to consider the issue of temperature regulation proactively.

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1. SETTING THE SCENE

1.1 URBAN GREEN INFRASTRUCTURE IN THE CONTEXT OF SOUTH AFRICAN CITIES

Cities are increasingly seeking to identify successful climate adaptation strategies as well as promote a general shift towards more sustainable development pathways. In this context, green infrastructure is increasingly recognised by policy-makers, academics and practitioners as an important complement to conventional 'grey' infrastructure in urban areas (European Commission 2015; Ramaswami et al. 2016). Green infrastructure is "the interconnected set of natural and man-made ecological systems, green spaces and other landscape features. It includes planted and indigenous trees, wetlands, parks, green open spaces and original grassland and woodlands, as well as possible building and street-level design interventions that incorporate vegetation. Together these assets form an infrastructure network providing services and strategic functions in the same way[1] as traditional grey infrastructure" (Culwick & Bobbins, 2016:7). We focus here on living systems specifically, excluding green technology such as renewable energy systems and sustainability issues more generally. Green infrastructure has been used in African cities to include private spaces (such as gardens), tree plantations, rangelands and urban forests (Mensah, 2014).

Urban green infrastructure plays a vital role in providing ecosystem services to cities. Ecosystem services are benefits generated by natural processes, often categorised broadly into four categories: regulating services (e.g. temperature regulation), provisioning services (e.g. providing physical goods such as food crops or building material), cultural services (e.g. recreation opportunities) and supporting services (e.g. habitat provision) (du Toit et al., 2018). These services benefit urban residents directly but can also be helpful for cities' climate change adaptation and mitigation strategies, for example planting trees to absorbs CO_2 emissions (mitigation), or provide shade to help residents cope with rising temperatures (adaptation) (Demuzere et al., 2014). As such, green infrastructure performs vital roles in mitigating the growing risks in cities associated with rapid development and climate change (flooding, heat stress, air pollution, etc.). It also helps ensure general urban sustainability, by generating critical resources through services such as water filtration, storage and recycling.

Internationally, cases have demonstrated that nature-based systems in some instances provide critical services in a more cost-effective way than conventional solutions (Postel & Thompson, 2005; European Commission, 2015). Urban green infrastructure can even help mitigate negative impacts of traditional infrastructure, such as the contribution of paved surfaces to heating urban areas (the 'urban heat island' effect, see section 1.2). In the right context, nature-based approaches hold the potential of being more sustainable in the long run than conventional solutions to adaptation, and also of being able to provide a range of other benefits to society (e.g. Kithiia & Lyth, 2011; Naumann et al., 2013; Wertz-Kanounnikoff et al., 2011). For instance, in a study that valued the natural assets of the City of Cape Town, decision-makers ranked natural hazard regulation, recreation and tourism, water purification, habitat and aesthetic value as the most important ecosystem services for the city (de Wit et al., 2012). The study authors conservatively estimated that for the City, natural assets yielded a flow of ecosystem services valued in the order of R4 billion per annum, within a range between R2–R6 billion per annum (the values reflect 2008 figures), which at the time equated to c. 10%–25% of the total annual municipal budget. Despite this value of green infrastructure, implementing and maintaining such projects within African cities has often taken a back seat to the provision of more urgent basic services such as housing, transportation and education facilities (Goodness & Anderson, 2013; Gwedla & Shackleton, 2015; du Toit et al., 2018; see also section 3.1).

The *National Strategy for Sustainable Development and Action Plan* outlines the national government's commitment to follow a pathway of green growth and respond to the growing concerns of climate change (Department of Environmental Affairs, 2011). "Green growth" is intended to ensure economic development while transitioning to a more sustainable and resilient development pathway. While national in origin, the commitment is to be carried out across all levels and sectors of government including municipalities. Green growth pathways are not only important for shifts towards environmental sustainability but are vital in building city resilience through well-functioning ecosystems that can provide critical services and mitigate environmental risks (Bobbins & Culwick, 2015). Green infrastructure strategies need to align concepts of green infrastructure with development priorities across all sectors in cities, in order to place social and ecological needs side-by-side instead of in opposition. In this way, cities can meet key development priorities while also preserving and benefiting from the services generated by natural ecosystems (Schäffler & Swilling, 2013; Culwick & Bobbins, 2016; Chu et al., 2017).

[1] We highlight however that while green infrastructure can generate the same services as conventional infrastructure, it does so based on ecological rather than engineering processes which requires fundamentally different skillsets and resources for effective management and maintenance.

1.2 URBAN GREEN INFRASTRUCTURE FOR HEAT REGULATION IN SOUTH AFRICAN CITIES

In South Africa, as in many other parts of Africa, urban areas are growing rapidly. This includes both urban sprawl as well as densification, both of which often happens informally in unplanned settlements and even faster through the creation of backyard dwellings (Hamann et al. 2018). Densification often implies encroachment on existing greenery and ecological processes, thereby threatening the benefits generated by urban green infrastructure. This can have consequences for a wide range of issues including flooding, water scarcity, air pollution, and public health. However, this paper focuses on green infrastructure's role in one of the most immediate impacts of urbanisation: the changes in local climate through the Urban Heat Island (UHI) effect (e.g. Tshwane: Adeyemi et al., 2015). UHI refers to temperatures within cities being higher than the surrounding rural areas, due to factors including air pollution, urban construction materials absorbing more heat than natural land cover, loss of cooling from plants' evapotranspiration, and engines and machinery generating excess heat (e.g. Levermore et al. 2018; Roberge & Sushama 2018).

The urban heat stress is expected to become an increasing issue under climate change (Roberts & O'Donoghue, 2013; IPCC 2014), putting South African cities under a dual pressure of urbanisation and increasingly common and severe high temperatures. Temperatures are rising much faster in South Africa than the global average, with projections expecting temperature increases of 3-6°C expected by the end of the century, and the country's cities are expected to be hotspots for climate change impacts (Ziervogel et al., 2014). The increase in temperatures is likely to amplify the UHI effect resulting in temperature extremes within South African cities. Informal settlements are already particularly vulnerable to climate-related stresses, and have been found to have much higher levels of UHI as a result of the types of building materials used, settlement density and lack of vegetation (Scott et al., 2017); townships and informal settlements have very limited green infrastructure in the form of trees and other vegetation (e.g. Maree & Khanyile 2017). Meanwhile in formal areas, densification is often seen as promoting energy efficiency and reducing CO_2 emissions – but risks leading to fewer green spaces and amplified UHI effect locally.

The impacts of heat are expected to be dire if not planned for and adapted to. Climate change will amplify the UHI effect, which creates health risks, stress and discomfort for residents (Ziervogel et al., 2014). Health effects include risk of heat strain, infectious diseases, noncommunicable diseases, and studies show a strong relationship between both morbidity and mortality and an increase in temperatures (e.g. Honda et al., 2014; Scovronick et al., 2018; Kingsley et al., 2016; Amegah et al., 2016). Aside from human health, heat in urban areas also impacts infrastructure and service delivery. For instance, elevated temperatures stretch existing health systems and impedes the productivity of workers and therefore personal incomes and urban economies (e.g. Kjellstrom et al. 2016), including through effects on the tourism sector. Higher temperatures can increase energy and water demand, with implications for meeting such demand on energy and water supply, delivery and maintenance of infrastructure. In particular, the people who are likely to be the most vulnerable to the negative impacts of temperature rise are the least socio-economically advantaged, given their generally lower levels of adaptive capacity. For instance, the highest morbidity and mortality associated with extreme heat appear to fall disproportionately upon marginalized groups including the poor and minorities (e.g. Yardley et al. 2011).

Green infrastructure mitigates heat through increased plant transpiration (water emitted from the surface of plants' leaves, stems and flowers, which requires energy and thereby cools the air) while providing shade for underlying surfaces such as streets (Bolund & Hunhammar 1999). The effectiveness of these functions is largely dependent on the form and size of individual areas of vegetation, as well as the distance and ecological linkages between multiple areas in the urban landscape. Parks and open green spaces have a significant impact on cooling, however mostly on a neighbourhood scale. For temperature reduction in cities more broadly, a combination of street-side trees, green walls and green roofs can be more effective (Herath et al., 2018). A number of studies have shown the significant potential of greening to reduce city temperatures. For example, trees in downtown urban canyons can reduce air temperatures by as much as c. 4 °C (Loughner et al., 2012). Trees in residential neighbourhoods can decrease local ambient temperatures by roughly 0.5-2.7 °C (e.g. Shashua-Bar et al., 2009; Sung, 2013; Ellis et al., 2015). A study of tree planting throughout the Los Angeles basin (California) found reductions in late afternoon temperatures of up to 1.7 °C for the metropolitan area as a whole, offsetting much of the city's average summer heat island effect (Rosenfeld et al., 1998). The open greenspace of urban parks results in much cooler temperatures within them compared to the surrounding city. Across a number of studies, the magnitude of this effect has been shown to range from roughly 1.5 to 4 °C (Shashua-Bar et al., 2009; Bowler et al., 2010; Doick et al., 2014; Sugawara et al., 2016) and to extend beyond the park's boundary. Even small urban greenspaces have been observed to make a big difference in local temperature, up to 6.9 °C in one study (Oliveira et al., 2011). In general, vegetation integrated into buildings and open green spaces have a lower potential for cooling as well as carbon sequestration compared to urban trees and forests (TPL, 2016). However, since different ecosystems can function differently depending on seasons and time of day, combining different types of green infrastructure can help ensure a more reliable provision of cooling and other benefits across city landscapes. These benefits

indicate that green infrastructure can play an important role in adapting South African cities to the growing risks of heat due to climate change and urbanisation. There is a need to acknowledge that residents do not necessarily value or benefit from green infrastructure equally. Research indicates that social class and education affects how people perceive green infrastructure: residents in poor communities tend to place highest value on provisioning ecosystem services that generate tangible benefits like food, raw materials and water, while university students and staff place more value on regulating services that deliver more general benefits like carbon sequestration, water purification and disease control (du Toit et al., 2018). These are important considerations for city planners and decision-makers who are responsible for equitable service provisioning to residents, as well as for building public support for prioritising green infrastructure solutions to mitigate heat problems.

Finally, and as mentioned previously, while this paper focuses specifically on the temperature regulation potential of urban green infrastructure, it is important to emphasise again that multiple co-benefits can be realised from greening within cities. For example, the sustainable management of stormwater based on water-sensitive design approaches can simultaneously fulfil some of the greening requirements for temperature regulation as well as other objectives (e.g. European Commission, 2015). As another example, greening programmes can translate into energy savings and reduced greenhouse gas emissions. For example, one study found that a 10% increase in shade coverage reduces electricity consumption by 1.29 kWh per day on average for residences in a suburban environment (Pandit & Laband, 2010). Greenery can provide a range of other important services including restoring local water balances, improving socio-economic opportunities within cities by supporting tourism and boosting property values, and buffering against hazards such as floods or coastal storm surge (e.g. de Wit et al., 2012; Coutts et al., 2013). These co-benefits reduce competing space requirements between green infrastructure and other forms of infrastructure, as green areas can serve more than one function and provide a range of benefits.

1.3. RATIONALE AND STRUCTURE OF PAPER

The observed benefits of urban greenery and the expected increase in climate-related risks within cities make it vital for local governments to consider green infrastructure solutions in development and climate change strategies. This paper focuses on three metropolitan municipalities: Mangaung, Johannesburg and Cape Town. The first municipality was included to gather insights about challenges in a city where green infrastructure is not yet used. The second and third have made more progress in this regard, and were included to capture experiences from two different local climate conditions – inland and coastal, respectively.

Based on interviews with fifteen key informants – twelve municipal staff across different environmental, city planning and parks departments, complemented by three private sector consultants – we investigate to what extent these local governments plan for or use green infrastructure, and what are the key barriers and enablers to implementing such approaches. The paper adds to a growing number of studies on green infrastructure planning and implementation in South Africa (e.g. de Wit et al. 2012; Cilliers et al., 2013; Schäffer & Swilling, 2013). By exploring the relatively understudied topic of green infrastructure and heat mitigation, we complement previous work on how green infrastructure influences stormwater and flood mitigation (Rebelo et al., 2015; Mander et al., 2017). Further, unlike many other effects of climate change, where the time and location of impacts are difficult to predict, temperature increases are the most certain climate impact across Africa (Niang et al. 2014) including South Africa (Mambo & Faccer 2017). This will manifest both as more frequent heat waves, as well as chronic and long-term increases in daily temperatures.

Based on this, the paper aims to help fill an important policy and practice gap and provide direction for cities to consider the issue of temperature regulation proactively. As the paper will show, work on urban green infrastructure in South African cities is in its infancy, and heat is not yet considered a priority in the context of such projects. Acknowledging this, we centre our discussion around barriers and enablers to green infrastructure implementation more generally, while reiterating that temperature regulation remains a priority policy and practice gap. The barriers and enablers focused on here are those that respondents described most frequently and in most detail; the scope of this paper also means that other points made during interviews have been left out.

2. CASE STUDY CITIES

The three cities (Cape Town, Johannesburg and Mangaung) differ considerably in their adoption of green infrastructure approaches, in a way that seems to mirror their respective engagement with climate change issues historically. This section introduces the three cities by briefly describing the current status of climate change and green infrastructure work, attention to temperature issues, and what understood demand there currently is from the public.

At the time of the study in late 2018, the City of Cape Town Metropolitan Municipality (CoCT) had the most advanced explicit agenda on green infrastructure, with the appointment of a staff member to develop a green infrastructure plan (though the plan is in its very initial stages). CoCT respondents felt that the City is taking climate change seriously, recognising various

impacts and threats including heat. This has not yet translated into much practical work on green infrastructure to regulate temperature, however. There is some demand for trees among Capetonians, particularly in previously disadvantaged areas where there is a relative lack of green infrastructure present.

The City of Johannesburg Metropolitan Municipality (CoJ) has also made considerable progress. It has a climate change strategy and is reviewing its adaptation strategy, and it has commissioned an external body to produce a green infrastructure strategy. Similar to Cape Town, respondents felt that CoJ accepts the importance of the climate change threat. Heat is generally considered as a growing problem, but green infrastructure is not used to explicitly address this problem. However, respondents from the Air Quality and Climate Change section of Johannesburg's Environment and Infrastructure Services department did highlight heat as a priority area that has emerged from the current process of reviewing the city's adaptation plan. They acknowledged multiple impacts of heat on the city, the intention to develop a heat management plan, and the important role of green infrastructure in mitigating heat. This represented a greater awareness of heat risk compared to other respondents in this study. As for public appreciation for green infrastructure, CoJ respondents reported that rather than a demand for more green space, residents tend to request more maintenance of existing areas. Green infrastructure was also seen as unevenly distributed between previously disadvantaged areas and wealthier neighbourhoods.

In Mangaung, respondents were not generally using the green infrastructure concept. This could be an effect of the City only engaging with climate change issues very recently: examples from CoJ and CoCT show that green infrastructure is typicaly introduced in the context of climate change policies. They noted that the municipality does not have access to much knowledge about climate change impacts in general, nor the capacity to address such issues. Respondents expect climate change to make Mangaung hotter, drier and more drought-prone, but there is a keen interest to engage with the university scholars and other experts to learn more. Consultants have developed a climate change strategy for Mangaung, but the city council has yet to approve it. Interviewed civil servants were aware of benefits of using greenery especially for water management, but limited financial resources prevent more projects from being executed. Climate change or green infrastructure does not play a significant role in shaping the municipality's agenda, and conventional 'grey' infrastructure is currently the favoured approach for addressing the city's water scarcity issues.

While the studied cities did not have any projects explicitly labelled as green infrastructure, especially not in addressing rising temperatures (see section 4.6), there are examples of projects where the cities are using similar principles to deliver other ecosystem services. In Cape Town, for example, the Hout Bay Dune Rehabilitation Project seeks to manage the movement and migration of sand dunes to prevent them from encroaching on roads and private property. The dunes have been re-profiled, wind-netted and planted with dune-specific vegetation, which has assisted in restricting the movement of the sand. This demonstrates that the principles of green infrastructure are already being applied in some cases, but that the heat issue is not yet a focus of projects.

3. BARRIERS TO GREEN INFRASTRUCTURE PRACTICES IN SOUTH AFRICAN CITIES

Implementing and maintaining green infrastructure is complex, not least in the South African context. While national government supports a green growth agenda and climate action (Montmasson-Clair, 2012), municipal governments have a considerable role in implementing the necessary action. Often the environmental priorities and perceptions of local governments have a determining factor in how cities incorporate green infrastructure into fiscal planning (Goodness & Anderson, 2013, Cartwright & Oelofse, 2016). Many of the barriers we discuss below are interrelated, and separating them out is therefore something of an artificial exercise; we do so here to ease the flow of the document. Because there is limited work from South African cities that focuses on green infrastructure specifically in relation to heat mitigation our discussion on barriers and enablers to implementation considers green infrastructure in more general terms.

3.1. SEEING THE BENEFITS

Respondents commonly reported that the "worldviews" of certain municipal actors and departments act as barriers to implementing green infrastructure. As a new concept in South Africa, green infrastructure does not fit into established ways of planning and managing cities; for instance, one respondent noted that national infrastructure grants do not cover nonconventional ways of delivering infrastructure. Most progress towards acquiring knowledge about and appreciation for the value of green infrastructure was reported among those tasked with environmental management. This might not be surprising, but poses a potential problem since implementation and maintenance of green infrastructure typically require cross-departmental collaboration. Some respondents attributed these differences in perception to the idea that "conservation" and "development" are opposing objectives. This perceived trade-off between green infrastructure and the development needs of the city is also seen for other initiatives to make public management 'greener', such as climate change adaptation (Pasquini et al., 2013). Previous studies have reported that decision-makers within local governments in South Africa often place a low

priority on strategies to develop green infrastructure (Gwedla & Shackleton, 2015; Cartwright & Oelofse, 2016). Typically, economic inequality and the demand for housing and other developmental needs (e.g. roads, clinics, commercial space, etc.) are seen as urgent and place considerable pressure on municipal responsibilities and resources. For example, with reference specifically to housing, many cities have implemented urban densification plans to address housing shortages (see Goodness & Anderson, 2013, for a Cape Town example) and national government supports dense low-cost housing as part of the provisioning of housing in the Reconstruction and Development Programme (ANC, 1994). These efforts provide housing for previously disadvantaged groups, but limit the space available for green infrastructure (Gwedla & Shackleton, 2015), as do other developmental imperatives. Furthermore, as pointed out by one interviewee, the concept of green infrastructure is not accommodated in current models and systems for categorisation and evaluation of projects. Since this is what determines budget allocation, inadequate or incorrect 'substitute' categorisations fail to capture their benefits which means that conventional infrastructure projects are more likely to be seen as better options. For example, current systems typically only deal with monetary valuations rather than more complex assessments of the full life cycle of projects as well as the full range of ecosystem service types.

Half of respondents suggested that this perceived trade-off can be remedied by making more explicit what social and economic value green infrastructure provides through ecosystem services (see section 4.1). This can help integrate it as part of development towards more 'liveable' city spaces that are more resilient to global changes (see section 4.6). Similar solutions have been suggested in academic literature, which has however also pointed to the constraint posed by a lack of adequate systems for ecosystem services valuation (Cilliers et al., 2013; Schäffler & Swilling 2013). Many approaches to assess natural capital tend to result in very high monetary values, but values that appear abstract because they cannot be converted into municipal revenue chains (Cartwright & Oelofse 2016). As a result, the apparent lack of market value for the direct benefits of green infrastructure often encourages developers and landowners to transform natural land in favour of land-use types which provide direct economic benefits (Cartwright & Oelofse 2016; Dhakal & Chevalier 2017). In other words, the lack of data, management tools and assessment methods available to local governments obstructs the ability for cities to incorporate the value of ecosystem services into planning and practice (Jorgensen et al. 2016; du Toit et al. 2018).

3.2. BREAKING "PATH DEPENDENCIES"

A third of respondents mentioned that local governments prefer to engage with conventional "ways of doing things", indicating a bias towards the status quo. Since grey infrastructure has been the norm, this is where municipalities have tended to build up skills and experience. Roles and responsibilities are often better defined for conventional approaches than for green infrastructure projects. For example, one interviewee mentioned the challenge of working with projects that rely on trial-and-error and have unpredictable outcomes depending on external conditions like rainfall and climatic variation; here, professional liability deter engineers and others that are accustomed to be able to deliver more predictable outcomes. Studies have also shown that path dependency can also shape planning standards and regulations, which end up favouring conventional infrastructure unless they are explicitly designed according to ecological principles (e.g. where permeable surfaces replace paved ones as standard practice) (Dhakal & Chevalier, 2017). Interventions using green infrastructure to reduce risks and improve well-being are often poorly incorporated into financial planning as they do not fit into existing institutional practices and local governments are unaccustomed to them (Cartwright & Oelofse, 2016).

This phenomenon is known in literature as "path dependency", whereby past decisions can influence and constrain future choices leading to difficulties in breaking away from a specific development pathway. For example, once investments have been made in particular technologies and associated infrastructures, it is often less costly to proceed on that path rather than to reverse or change it by moving to different technologies and infrastructures. Path dependency has been shown to inhibit green infrastructure when decision-makers apply the same economic planning criteria used for grey infrastructure to value and rationalise green infrastructure, instead of adopting new ones (Matthews et al. 2015; Enqvist et al. 2016).

3.3. PRACTICAL IMPLEMENTATION

Another set of constraints that emerged from interviews related to the practicalities of putting green infrastructure into practice. Specifically, there are several knowledge gaps regarding the details of operationalising green infrastructure, i.e. putting it in place and maintaining it, including how to integrate it with existing conventional infrastructure, and knowing what ecological functions to promote to cope with climate risks. Some respondents also noted the need for context-specific data and knowledge, especially regarding the risks associated with heat and how green infrastructure might help cities mitigate them. The literature has recognised that local governments face challenges in understanding the principles and outcomes of green infrastructure and integrating them into the current planning and practice (Matthews et al., 2015). Some challenges stem from the fact that green infrastructure and the services it generates are a function of the interactions between living ecosystems and human activities (Andersson et al. 2014). This implies a different way of functioning and

different management needs compared to engineered, technology-based alternatives (Schäffler & Swilling, 2013), for example developing evaluation criteria that account for the complexity of living systems that is typically ignored by engineering and grey infrastructure solutions (Matthews et al., 2015). This tension was in various ways recognised also by respondents who brought up how green infrastructure and conventional infrastructure are very different, which means that the former will require different skills, equipment, scheduling and resources to maintain – which generally are currently lacking in South African cities. As an example, previous research has shown that green roofs (which generate various benefits for heat regulation) are comparatively expensive and require technical expertise which cities often lack (Zhang et al., 2012).

A few respondents explicitly noted that green infrastructure is one of many new concepts that keep being introduced to urban management, many of which overlap considerably in meaning. Similar concepts that were mentioned and often had a longer history include biomimicry, metropolitan open space systems, landscape ecology, ecological infrastructure, etc. This multitude of concepts and approaches complicates the implementation of all of them.

3.4. BREAKING INSTITUTIONAL SILOS

As noted in Section 3.1., investments in, planning for and maintenance of green infrastructure solutions are impeded by the separation of responsibilities between policies and visions developed in environmental or climate change departments, and the practicalities of implementation falling on various other departments responsible for green spaces and service delivery. This is clear for both CoCT and CoJ, where several policies explicitly recognise green infrastructure, but where some respondents note that very few projects have been implemented to make such policies reality. A couple of interviewees also noted that implementation itself is impeded by divisions between municipal departments, known as "institutional silos" that prevent collaboration among sectors and departments (e.g. Burch, 2010; Froestad et al., 2012). Institutional siloing has also been identified in literature as an impediment to implementation and maintenance of urban green infrastructure in SouthAfrica (Mensah, 2014; Culwick & Bobbins, 2016; Mekala & MacDonald, 2018). It can result in insufficient funds being assigned, leaving the entities mandated to deal with green infrastructure under-capacitated to successfully carry out green infrastructure projects (Schäffler & Swilling, 2013; Mensah, 2014; Jorgensen et al., 2016; Mekala & MacDonald, 2018). Another challenge is the lack of clarity around who is responsible for the infrastructure. In the temperature regulation example, public health services might have an interest in investing in green public spaces without any formal authority to do so; similarly, parks departments might be able to invest but unable to recognise the benefits it would generate for public health. This raises the need to coordinate green infrastructure strategies across municipal and other public sectors.

To summarise, interviews and previous literature show that green infrastructure require efforts to break with previous ways of operating. This is impeded by path dependency, prevailing worldviews, difficulties in accessing knowledge and data, a need for tools to demonstrate economic value of ecosystem services, institutional silos and inadequate municipal skill-sets (Mensah, 2014; Dhakal & Chevalier, 2017). The following section presents possible approaches for addressing these issues, starting with a summary of insights from previous studies and interviewees' knowledge, then also adding suggestions from the authors of this paper.

4. FACILITATING IMPLEMENTATION OF GREEN INFRASTRUCTURE PRACTICES

4.1. TOOLS TO ASSESS VALUE OF ECOSYSTEM SERVICES

Green infrastructure approaches can be facilitated by better tools to assess economic value of ecosystem services in general. Linking such tools to existing city planning can help municipal governments understand the benefits of green infrastructure and integrate it into decision-making processes (Culwick & Bobbins, 2016). For instance, CoCT has commissioned a report to evaluate of the city's natural assets that shows how Cape Town's greenery provides both economic benefits, a basis for livelihoods and well-being for local communities (de Wit et al., 2012). This report was known and mentioned by multiple CoCT interviewees, which further supports the need for such information.

Interviews also showed that knowledge specifically about climate-induced heat threats is largely lacking among the studied municipalities. This gap is an important barrier to overcome, and research is needed both to understand the heat threat better, and to understand how heat mitigation from green infrastructure can be included in ecosystem service assessments for South African cities. Mechanisms will also be necessary to transmit this research to cities, potentially through partnerships or networks (see Section 4.3).

As for evaluating green infrastructure approaches specifically, these have much in common with so-called "ecosystem-based adaptation"[2], which has been evaluated in Durban. Cost-benefit analysis showed relatively poor economic performance of ecosystem-based adaptation over the short term compared with other adaptation interventions, likely due to high

2 Ecosystem-based adaptation is defined as the use of biodiversity and ecosystem services as part of an overall adaptation strategy to help people adapt to the adverse effects of climate change (e.g. Munang et al., 2013). For an example in flood risk reduction, this would include the maintenance and rehabilitation of wetlands and catchments, rather than building canals and dams.

initial cost of purchasing land and restoring degraded ecosystems – both likely to be the case in most urban areas (Roberts & O'Donoghue, 2013). Economic feasibility improved over the long-term however, suggesting there is long-term value to investing in ecosystem protection and management (Roberts & O'Donoghue, 2013; Dunsmore, 2016), making these approaches particularly important in South African cities where the impacts of temperature increase will intensify in future years. Further, it should also be noted that the high cost of acquiring or restoring land to establish green infrastructure can be partially avoided by directing resources towards more localised efforts such as street tree planting and water-sensitive design in urban storm water drainage. However, it is important to be aware that green infrastructure typically requires continuous maintenance which means that it is vulnerable to budget cuts within departments responsible for maintenance (Mekala & MacDonald, 2018). Municipalities therefore need to be wary of proposals that do not clarify what functions the green infrastructure will provide and what maintenance measures are required (Dunsmore, 2016; Dhakal & Chevalier, 2017). In South Africa, these assessment tools need to be integrated into broader development efforts to ensure that green infrastructure benefits those that are most vulnerable to the impacts of climate change – including those who are more vulnerable to heat (e.g. the elderly, infants, people with pre-existing medical conditions), and those who have less access to green infrastructure compare to others (Chu et al., 2017). Importantly, conventional and typically monetary valuation criteria associated with grey infrastructure solutions are often poorly equipped to assess the broader range of benefits humans derived from green infrastructure in addition to their primary function (Schäffler & Swilling, 2013). Here, social learning methods that rely on collaborative teams to identify green infrastructure assets and their benefits have been shown to be useful for developing shared goals that account for more vulnerable populations and management approaches to reach them (Mander, 2016). Participatory decision-making tools like these can help to reinforce municipal commitments to implementing and maintaining green infrastructure, and also help identify ecosystem disservices, e.g. how natural processes risk harming humans (Cilliers et al., 2013).

4.2. LEVERAGING EXISTING POLICY/LEGISLATIVE TOOLS

A few respondents noted that there is already scope within existing legislation to "do creative things" for green infrastructure implementation. For instance, new municipal by-laws can be created to facilitate green infrastructure implementation; existing regulations around Environmental Impact Assessments and guidelines for issuing development and building permits can be adjusted to include green infrastructure requirements. One CoCT interviewee reported discussions around creating an environmental by-law to enact protected areas to protect ecologically-valuable land. Another respondent provided the example of the conservation servitudes approach in Durban, whereby the outcome of a development assessment process can require the registration of a conservation servitude over the portion of the application property that has been included in the Durban Metropolitan Open Space System, or which contains conservation-worthy biodiversity, or is providing valuable ecosystem services. A review of literature on the benefits of green infrastructure for heat mitigation and emissions reductions in cities suggests that from a policy perspective, tree protection standards requiring tree removal permits and minimum tree sizes for replanting can greatly reduce the UHI (TPL 2016). One study finds that neighbourhoods with such policies have on average c. 1.5 – 3.8 °C lower surface temperatures than similar neighbourhoods without such policies (Sung, 2013).

The literature suggests that standards which enforce green infrastructure design regulations are vital for enabling cities to combine development and housing needs with provision of green infrastructure (Zhang et al., 2012; Dunsmore, 2016). This includes creating new fiscal policies for green infrastructure, such as the "special rating areas" tool from the eThekwini municipality where an additional levy is applied to land identified as critical to ecosystem services which allows additional funding to be funnelled towards the management of green infrastructure on this land (Roberts & O'Dongoghue, 2013). Strategies like this could be extended to the private sector through creating new funding and incentive mechanisms for green infrastructure (such as the payments for ecosystem services sometimes used internationally) and creating tax reductions for green infrastructure projects (Dunsmore, 2016; Dhakal & Chevalier, 2017).

Globally, some cities are seriously engaging with the issue of increasing temperatures, and taking action. For instance, Tokyo has been taking measures since 2000 to mitigate the UHI effect, including covering roofs and walls with greenery. These measures include the passing of a Nature Conservation Ordinance in 2001, which requires the greening of building roofs and walls, in addition to ground-level greenings, for all new construction as well as existing buildings undergoing renovations (C40 Cities, 2015). As another example, Toronto adopted a Green Roof Bylaw in 2009, a by-law that both requires green roofs and establishes the construction standards for them (City of Toronto 2019a). The by-law allowed the city to require green roofs, as opposed to the previous approach, started in 2006, of encouraging green roofs for new private development. Toronto also has an Eco-Roof Incentive Program, through which grants are available to support the installation of green roofs and cool roofs on Toronto homes and buildings (City of Toronto 2019b).

Looking ahead, it is important that spatial planning and strategies for e.g. densification and transit-oriented development are devised in a manner that don't result in increased temperatures and thus exacerbate heat-related problems. As such, attention needs to be paid to developing conditions relating to minimum greening and landscaping requirements, choice of materials with reduced heat absorption qualities and so forth.

4.3. COLLABORATIVE PARTNERSHIPS AND NETWORKS

Respondents mentioned the importance of promoting "new ways of doing things" and building knowledge and technical capacity for green infrastructure. This includes collaboration between municipal departments, as coordination of objectives and actions is important for effectively implementing green infrastructure projects. Further, collaboration with other societal sectors and stakeholders is vital to shift viewpoints and create shared values between different actors (Bobbins & Culwick, 2015). A couple of respondents suggested investments in relevant partnerships with local non-governmental stakeholders that have similar agendas as municipalities. Forming collaborations between departments in local governments and targeted actors (such as developers and landowners) has also been recognised as an enabler to facilitate the shift in path dependency in favour of green infrastructure (Zhang et al., 2012; Chu et al., 2017). Given interviewees' common reporting of a need for knowledge building regarding green infrastructure, suitable partners could be universities and research institutes (such as the Council for Scientific and Industrial Research, CSIR). In addition to short-term knowledge support to municipalities, this could also involve longer-term efforts including university programmes to train students in working with green infrastructure projects. The Mangaung case highlights the importance of University partners to help fill knowledge and capacity gaps, with one respondent stating:

> It is very important that we ... work with the university based on their research capacity to address this matter of climate change, because if you come to the municipality they don't have really the capacity to address the matter on a scientific basis.

Some interviewees also highlighted the importance of learning from international cases and experiences with green infrastructure and climate change in general. Partnerships with cities and universities might therefore be helpful, such as CoCT membership in the C40 Cities Climate Leadership Group which includes the "Cool Cities" network working to combat UHI issues (C40 Cities, 2019). All three studied cities are members of the global network ICLEI Local Governments for Sustainability, which provides knowledge and resources on urban nature-based solutions (ICLEI, 2019). For municipalities unable to make such commitments, dialogue and learning between South African cities might still be highly valuable.

4.4. ENGAGING LOCAL COMMUNITIES

Green infrastructure distinguishes itself from conventional alternatives because it can be suitable and even desirable to involve local communities in maintenance. Adequate upkeep is an important factor determining how much the public uses green spaces, partly because poor maintenance of parks and open spaces tends to also attract crime which deters regular users. In other cases, such as newly planted street trees, community buy-in can be essential for ensuring that the saplings are protected until they grow larger. As pointed out by one CoJ interviewee, maintenance of open green spaces is challenging in previously disadvantaged areas where problems of illegal dumping, squatting, burning, or other unlawful use of the land is more common than elsewhere. Similar points have been made in the literature, showing that open green spaces in South Africa can be undesirable for communities because of social nuisance (Donaldson-Selby et al., 2007; Cilliers & Cilliers, 2015). Such issues complicate cities' efforts to align long-term goals such as climate adaptation with the interests of local populations (Buijs et al, 2018), and can increase the maintenance cost of preserving green infrastructure that local communities see no value in.

There are many international examples of the positive effects of involving urban residents in designing, protecting and managing local green spaces (Nagendra & Ostrom, 2012; Connolly et al., 2013; Andersson et al., 2014), and tapping into the stewardship potential of local communities has been presented as key mechanism for achieving sustainable green infrastructure practices and overcoming maintenance (Goodness & Anderson, 2013; Enqvist et al. 2016). By aligning municipal agendas and civic action it is possible to form management approaches that are particularly important on land that are highly used by residents, or owned by private residents or other non-public entities (Goodness & Anderson, 2013; Buijs et al., 2018). The latter is particularly important as public funds typically cannot be spent on private land (Dhakal & Chevalier, 2017). The potential of collaborations with residents was recognised by respondents in Cape Town, who are aware of considerable civic engagement among residents for urban greenery. Respondents also noted that private land is an important part of the city's green infrastructure, even though residents typically do not use that term, and one reported that CoCT is working to improve collaboration with civil society actors on these issues.

It is widely recognised in green infrastructure literature that it generally needs to be managed as an interconnected mosaic or network, especially in urban landscapes (e.g. Andersson et al., 2014; Demuzere et al., 2014; Enqvist et al. 2016). This is required for ecological processes to function and provide the benefits humans desire, including combating temperature increases. For heat regulation, a single urban park will give limited benefit beyond the immediate surroundings, whereas a network of parks connected by green corridors such as street side trees is more likely to benefit temperature regulation in the city as a whole. However, the demand for land in cities often means that open urban land will be targeted for housing development rather than green infrastructure (Goodness & Anderson, 2013) and municipalities' economic interests are often

assumed to align with such development rather than large-scale green infrastructure (Gwedla & Shackleton, 2015). In this context, it is critical to acknowledge the benefits generated from privately-owned and informally-managed land, such as home gardens, cemeteries and even golf courses, often disregarded by planning authorities (Andersson et al. 2007). Better awareness of the lost opportunity and negative consequences of new development that does not incorporate green infrastructure can further help motivate alternative approaches that do.

Ideally, approaches that involve local residents and non-state actors can make otherwise labour-intensive upkeep of green infrastructure more cost-effective for municipalities, while also ensuring community buy-in. The success then sets a precedent for green infrastructure in the city while also creating local champions who can further the green infrastructure agenda (Roberts & O'Donoghue, 2013; Chu et al., 2017). Inviting community participation can help match critical areas for green infrastructure with the interest of local residents, which makes it easier to design green spaces that serve multiple functions (Goodness & Anderson, 2013; Buijs et al., 2018). Civic engagement does not imply that local governments no longer have a role to play, but rather that their roles need to shift towards new functions including driving the agenda and regulations for green infrastructure, coordinating action and knowledge-sharing between stakeholders, and capacitating stakeholders to carry out green infrastructure projects (Harrington & Hsu, 2018). However, collaborative approaches can also empower communities politically and economically, and bottom-up approaches can play a critical role in finding a way to break away from path dependency in municipal bureaucracies (Enqvist et al. 2016).

However, collaborative management should not allow for governments to shed responsibility and allow special interest groups to control use of public land since this risks unjust or unequal local participation of and benefit to local residents (Westman & Broto, 2018). One Johannesburg respondent pointed out that to the contrary, partnerships are likely to bring municipalities increased capacity requirements since the monitoring and enforcement load on the municipality will increase. Multiple Johannesburg respondents reported that partnerships bring a risk that the private stakeholders will shed agreed-upon responsibilities. The municipality has a difficult task to prevent this:

> You need to constantly be on the ball, you need to maintain responsibility and keep an eye on those people that have taken stewardship for [the green infrastructure], to make sure that they're not neglecting their responsibility. ... The fact that you will always have to contribute to it in your levies, becomes a grudge, particularly ... when everybody's economically pressed. And that's when it becomes difficult [and] when people want to start pulling out of these arrangements, and we've seen it with a couple of residential estates that have green infrastructure on them.

This respondent also noted that it is necessary to explore financial incentives to deal with these issues. Research has suggested that partnerships with mutual economic benefits is essential in ensuring long-term commitment from all partners (Khare et al., 2011). Here, there are important lessons to be learnt from rural South Africa, where clearing of invasive alien vegetation has employed thousands in the Working for Water programme (Department of Environmental Affairs 2019) while promoting water-related ecosystem services. Some respondents were well aware of this link between green infrastructure and employment opportunities, specifically due to the maintenance requirements. One respondent pointed out that this typically involves low-skill level jobs, which as the Working for Water programme has shown is of great importance for the South African labour market.

4.5. COMMUNICATING THE VALUE OF GREEN INFRASTRUCTURE

The ability of green infrastructure to compete with conventional alternatives is sometimes undervalued. This undervaluation does not come from the fact that green infrastructure has been shown to be inferior to conventional alternatives. Rather, it arises because, as an emerging, innovative approach, green infrastructure can suffer from a range of issues, such as poor design (due to lack of knowledge and skills), inadequate maintenance, or lack of appropriate resourcing. Communicating the value of green infrastructure is therefore more difficult when the competency to manage it has not yet been built up, and when both globally and locally, more experimentation and research around green infrastructure solutions and applications, and the different benefits produced by different applications under different conditions, is still necessary.

One way of circumventing this problem is to draw on work that has already been done under a different guise. Respondents discussing ongoing green infrastructure projects often pointed out that these are often not referred to or labelled using that term. One potential way of promoting green infrastructure approaches is therefore to demonstrate to cities that it is in fact something they already do or know about. For example, many respondents in Johannesburg and Cape Town talked about the benefits of urban greenery using ecosystem services language, mentioning benefits like: flood risk mitigation, recreation and "liveable" spaces, water infiltration and supply, storm surge protection, improved air quality, heat mitigation, and improved food security. This is a useful starting point, since it draws attention to the types of benefits also provided by conventional infrastructure. It is important to note, however, that green infrastructure functions based on ecological principles

which means connectivity between different green areas plays an important role in determining overall benefit generations.

Respondents report that recent environmental crises such as the Cape Town drought have drawn attention to the growing threat of climate change as well as the link to green infrastructure. This corroborates previous findings regarding the role of disasters and extreme weather events can play in catalysing change in cities (e.g. Carmin et al., 2012; Pasquini et al., 2015). It is important to note that previously disadvantaged and poor urban areas are often already more exposed to environmental risk, and also tend to have lower density of greenery (Gwedla & Shackleton, 2015). This makes it important to present the full range of social, economic and ecological value provided by green infrastructure; as a couple of respondents mentioned, to emphasise its contribution to creating more "liveable" city spaces that are more resilient to global changes. Further, we also argue that green infrastructure can be usefully integrated in urban planning and management through climate change policy – at least in cities like Johannesburg and Cape Town where climate change is acknowledged as an important threat. In the past, climate change was poorly understood and perceived as a simply environmental problem (e.g. Pasquini et al., 2013), which often left it ignored in broader planning and decision-making. While this problem might still persist in smaller municipalities in the country, the two biggest metros examined here demonstrate that local governments in South Africa are able to shift their views of climate change. Embedding green infrastructure in climate change strategies could facilitate successful implementation and can enable local governments to link it to specific adaptation and development goals across all sectors of government (Culwick & Bobbins, 2016). For example, research in eThekwini Municipality shows that all adaptation interventions feature strong ecosystem-based approaches (Roberts et al., 2012; Chu et al., 2017). Internationally, authorities in Taipei (Taiwan) use green infrastructure explicitly to mitigate the UHI effect in the city (Mabon & Shih, 2018). These examples show that incorporating green infrastructure into climate change strategies is a useful and relevant way for local governments to mainstream green infrastructure.

4.6. GREEN INFRASTRUCTURE EXPERIMENTATION

A few respondents noted how getting people to buy into the concept of green infrastructure is complicated, as is making it "real" to people. At the same time, a few respondents highlighted that getting such buy-in from political and administrative actors within local governments, as well as the general public, is crucial for its success. How, then, to do so?

In this respect, creating "experiments" to see what works and what does not would seem one avenue to respond to the need, that some respondents identified, for demonstrating to people the value of green infrastructure through projects on the ground. We suggest that it might be prudent for such initiatives to start small-scale, given the resource constraints of cities and their multiple competing priorities, as well as the need to experiment, fail and readjust approaches. However, the potential for subsequent upscaling should also be taken into account. Such experiments would not only bring the benefits of green infrastructure "to life" for people, demonstrating its value. They should also provide the opportunity to: gain context-specific knowledge, as the respondent quoted above mentioned; undertake some forms of cost-benefit or valuation analyses (engaging the appropriate researchers/consultants); and provide learning-grounds for building up the required technical skills bases. In this manner, green infrastructure experiments could begin to address a number of the identified barriers.

Green infrastructure experiments can be an important tool for re-thinking urban development and integrating the planning of housing and green spaces. Given the urgent need for increased quantity and quality of housing in South African metropolitan areas – especially in previously and currently disadvantaged neighbourhoods – this represents one of the most critical challenges. The benefits of green infrastructure need to reach all members of society, and therefore cannot only be based on solutions that require setting aside vast areas of greenery where human activity and residence is entirely excluded.

5. CONCLUSIONS

Threats from climate change are no longer an abstract projection but increasingly tangible realities impacting South African cities. This adds additional stress on local governments already struggling to deliver national government's green growth agenda, service delivery development goals and manage the negative consequences of urban development. Cities are especially exposed to the direct effects of more extreme heat, as urban development transforms land cover thereby greatly amplifying the effect of local temperature increases caused by climate change (Cavan et al., 2014; Di Leo et al., 2016). Ongoing urbanisation also means that there is a pressing need to ensure that the cities of tomorrow are planned proactively to avoid committing to a development trajectory that exposes them to the combined heat effect of both climate change and urbanisation.

Urban green infrastructure holds great potential in mitigating urban heat issues, and also contributes a range of additional ecosystem services such as recreation, water regulation and air purification. While green infrastructure is receiving increased attention in South Africa's main metropolitan areas, it is underutilised as a tool to combat heat. This paper identifies several ways to make better use of its potential: improved ecosystem service assessments, using existing by-laws and building standards, cross-departmental collaborations, partnerships with non-governmental actors and local communities, linking the green infrastructure concept to climate change policies and the ecosystem services discourse, and allowing for

experimentation.

It is important to note that green infrastructure is based on living organisms and ecological processes, which means that it typically requires radically different management practices compared to conventional options. It can be costly, especially where are not also resources and knowledge about how to maintain and sustain its function. There are great gaps in data and information from real life case studies about the impacts of urban heat and potential mitigating effect of green infrastructure (on energy consumption, health and life expectancy, labour efficiency, equipment failures, etc.), as well as what types of vegetation best withstands the often harsh conditions that define South African cities (heat, drought, winds, flooding, and a range of types of pollution). If done properly, green infrastructure holds the potential of generating both environmental benefits, more liveable cities, reduced costs for other services, as well as large numbers of jobs especially for low-to-medium skilled labour.

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