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Green Infrastructure in Informal Settlements through a Multiple-Level Perspective

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ABSTRACT: The aim of this paper is to highlight limits in the current conceptualisation and implementation of urban Green Infrastructure (GI), particularly in informal settlements. We propose a Multi-Level Perspective (MLP) that helps analyse and identify opportunities to overcome such limits. The article starts by discussing the concept of GI and proposes its definition through the principles of multifunctionality, interlinkages and exchange. Recognising current gaps in implementation in the context of informal settlements, we argue for the better understanding of the range of socio-political conditions which enable or impede GI practices. To reflect on these gaps, the article uses MLP to explore persisting socio-ecological-infrastructural problems in water management, which could be perpetuated through current GI practices. MLP is used as a heuristic framework to analyse influencing factors that exist at multiple interconnected societal and bio-physical levels. The framework is applied to the city of São Paulo in Brazil where traditional water management has resulted in tensions between social and ecological systems between the regime (which encompasses institutional structures) and the niche (where innovations emerge, for example through grassroots movements). Examples of community initiatives are used that demonstrate a disconnection between top-down structures and everyday practices. We conclude that if GI presents the potential to support a transition towards water management that benefits both social and ecological systems, further characterisation of the concept is required.

KEYWORDS: Green infrastructure, informal settlements, sustainability transitions, multi-level perspective, São Paulo, Brazil

INTRODUCTION

Each city exists and expends through a web of socio-ecological-infrastructural systems. These systems are interlinked and enable the existence and transport of elements, such as water and people, which interact with each other and with the broader environment. Principles of Green Infrastructure (GI) have evolved on the basis of repairing holes in the web or creating new branches to enable elements to interact with each other and with the outside world. At various edges of the urban net, informal settlements are not always in the trajectory of the flow of elements, and are in fact typically located where ruptures exist. This research seeks to explore the manner through which GI could contribute to building web branches for the active integration of settlements within this urban net.

This paper seeks to interrogate GI, as a concept and a tool, in urban development debates around the management of socio-ecological nested systems. Socio-ecological systems are defined here as human

and environment systems, which behave and evolve in a coupled manner and interact through endogenous and exogenous processes. According to Ostrom (2009) socio-ecological systems are composed of multiple subsystems, and of internal variables within these subsystems. Following Ramaswami et al. (2012), the infrastructural element is added to frame social-ecological-infrastructural systems as those which consider the integration of urban metabolism to articulate transboundary infrastructure supply chains, here with a focus on water. We emphasise the nested aspects of these systems, for example in the way urban governance structures produce outcomes at local level, which in turn feedback to affect these governance systems as well as larger systems.

Therefore, the article discusses not only potential values but also risks added by GI in the preservation and development of ecosystems at multiple scales, and the associated social outcomes. While practices of GI have been considered for a varied range of purposes to date, GI is considered here as non-conventional approaches to water management, including for flood mitigation and water filtration. The discussions focus on the context of informal settlements, defined as residential areas where inhabitants have no security of tenure vis-à-vis the land or dwellings they inhabit, and where services and infrastructure are typically lacking (UN-Habitat, 2015). For the case of São Paulo, we refer to *favelas.* The framework is developed to explore socio-political conditions that may enable/disable the establishment of GI in informal settlements. This is aimed to help build knowledge on conditions that can foster transitions towards more sustainable and inclusive water management approaches through GI that meets the needs and priorities of all.

The article starts with a literature review on GI, linking the concept to relevant disciplines and comparable concepts, from which it identifies key principles characterising it. It then explores gaps in its conceptualisation as well as limits to implementation practices, using informal settlements to highlight potential tensions in urban development. In consideration of these limits and building on the work of Herslund et al. (2017), a Multi-Level Perspective (MLP) theoretical framework was developed. The MLP is applied here to examine the socio-technical transition from traditional water management towards sustainable practices through green space development, with a focus on both social (informal settlements) and ecological systems (water ecosystems). Opportunities for using this framework are discussed within the context of São Paulo city, for the analysis of innovations and the enabling environment in which they exist.

GREEN INFRASTRUCTURE: MORE THAN 'GREEN SPACES'

From a planning tool to a problem-solving technique

The concept of GI has emerged and evolved at the crossroads of multiple disciplines, thereby causing disagreements about the time it was first coined as well as its definition. While the definition of GI remains blurry to many, that of Benedict and McMahon remains the most cited in the academic literature:

> […] an interconnected network of green space that conserves natural ecosystem values and functions and provides associated benefits to human populations (Benedict and McMahon, 2001).

However, an identification of the overarching principles of GI enables to retrace the concept to earlier paradigms. For example, according to Matthews et al. (2015), one of the earliest uses of the term 'infrastructure' as applied to parks and green spaces sought to redefine the public park as an extension of urban infrastructure (Rosenberg, 1996). As such, the infrastructural aspect of GI elevates the concept beyond 'green spaces' (and urban greening more generally) towards a more utilitarian level of importance. *Green* infrastructure is typically considered as opposed to *grey* infrastructure such as dams and concrete drainage pipes for flood mitigation, or energy-based water treatment plants. While it has predominantly focused on the development of functions that support water systems (including through

the notion of 'Blue/Green Infrastructure'), the concept has enlarged as it has been associated with a wider range of functions.

The growing range of benefits associated with GI that have been claimed by experts provides legitimacy to its implementation in a wide range of contexts. These emphasise that the materialisation of the GI concept goes beyond green parks, and that the range of benefits sought through its implementation requires interdisciplinary approaches. GI has been linked not only to physical functions (e.g. water infiltration, storage and drainage, carbon sequestration, biodiversity conservation), but also to psychological benefits (e.g. individual coping) and institutional and economic benefits (e.g. community cohesion and economic growth). As such, GI has therefore been adopted in multiple ways by a wide range of disciplines.

It is important to note that 'green infrastructure', as a term, has been predominantly used in urban studies and landscape planning, both academically and in practice (Mell, 2008; Austin, 2014; Hansen et al., 2017). Yet**,** while the emergence of this term in such disciplines is recent, the concept can be related to older principles from various disciplines. For example, designing landscapes to emphasise biophysical as well as socio-institutional dynamic interactions can be linked to the laws of ecology. The first law '*everything is connected to everything else*' refers to the idea that organisms create reciprocal relationships with their environments. This is linked to thermodynamic laws which demonstrate that ecosystems use energy fluxes to maintain organisation when affected by physical counterparts (Simon, 1977; Cropp. and Gabric, 2002). This can in turn be linked to theories of resilience applied in fields of disaster risk reduction and climate change adaptation.

Engineering provides further examples of influence on the concept of GI where it has been adopted as a problem-solving technique. In civil engineering, there are well-established theories and practices of the natural systems having influenced drainage systems. For example, grassed waterways and detention ponds have been developed to control urban runoff as well as erosion since the 1970s in Australia and North America (Douglas, 2016). Practices of Sustainable Drainage Systems (SuDS) have been institutionally adopted in England for flood control and coastal management (DEFRA, 2004). While civil engineering focuses more on the use and control of nature for social benefits, ecological engineering sits on a more conservationist side of engineering. In the 1950s, Odum developed basic principles of ecological engineering around self-organisation in ecosystem designs, systems thinking and ecosystem preservation on which GI principles are also based (Odum and Odum, 2003).

Our approach towards GI is closer to Geography in the way it explores the relationship between humans and *nature* (here acknowledged as a socially constructed concept). Although the GI has been poorly covered by the literature in this area, we recognise that the concept solicits reflections around the idea of codetermination between ecosystems and societies which are central to notable geographers such as David Harvey. Harvey's reflections (1996) highlight the manner through which historically-specific and geographically-specific sets of relations between systems affect the transformation of particular environments (Loftus and Royle, 2017). These understandings can greatly benefit GI planning which tend to separate technoscience from social systems (Matthews et al., 2015). Geography theories can also help explore the manner through which GI has framed nature as an instrumentalised element serving societies' needs. Through such an approach, we seek to bridge biophysical conditions, with social and political conditions in which GI is developed.

Characterising GI

GI has risen in parallel to other terms that are also concerned with the coexistence of ecosystems and human development, whether they are used as technical tools, management approaches or philosophies. These include Ecosystem Services, Low-Impact Development, Best Management Practice, Ecosystem-based Adaptation, Eco-Disaster Risk Reduction, Natural Capital, and the aforementioned SuDS. The emergence and development of each of these terms have occurred over a similar period of time,

following the rise of the sustainable development movement which is itself typically related to the 1987 Brundtland Report. Only a few academic studies have attempted to map these terms together and analyse characteristics that specify each of them, which has led many of these terms to be used interchangeably or to develop in isolation. Nevertheless, cross-learning between these concepts represents key opportunities to feed the GI literature, both to fill gaps and to identify its added value.

Nesshöver et al. (2017) cross-compared several of these concepts and categorised them as either 'problem-solving techniques' (which concerns green infrastructure and ecological engineering), or 'approaches to management' (for example, for ecosystem-based adaptation and ecosystem services approach). Reflecting on this, we argue that the infrastructural component of 'green infrastructure' has attracted technocentric approaches to urban governance, and thereby provided a means to legitimise urban greening approaches. Nonetheless, much can still be drawn on technical aspects from existing research on similar concepts to benefit GI. That includes research which has analysed the practical implications of ecosystem services management approaches that serve the purpose of improving services to populations most in need (Forsyth, 2015).

Three major principles associated with GI are highlighted for the purposes not only of characterising it in opposition to similar concepts, but also to explore its potential beyond technical considerations. As such, we propose a framing of these principles that aligns with that of Andersson et al. (2014) and enables to further consider the socio-political dimension of GI in its context of implementation:

- *Multifunctionality*: This refers to the compatibility of land uses, which join forces to create combinations of meanings and functions in one spatial area. The literature on land-use planning and management argues this creates possibilities for better symbiosis between social, ecological and economic systems (Costanza, 2001; Ahern, 2007; Mell and Roe, 2007). High human population density and limited space in many cities generate demand for such multifunctionality of space. This may however be subject to differing meanings and conflicting interests (Borgström 2009; Ernstson and Sörlin 2009; both cited in Andersson et al., 2014).
- *Interlinkages*: This is defined in physical as well as in socio-institutional terms. In physical terms, it refers to the implementation of locally implemented green measures ('hubs') which are connected with each other through 'corridors' to form a GI at water-basin scale. This principle is well-established in the literature on GI (e.g. Benedict and McMahon, 2001; Schäffler and Swilling, 2013). Although less understood, this also considers the notion of socio-institutional integration, for example in the way landscape designs enable better connectivity of an area with others (Parikh et al., 2012), or at individual level by providing a space in the city that supports personal well-being (Germann-Chiari and Seeland, 2004).
- *Exchange*: Echoing theories of metabolic flows, this principle relates to the way systems create reciprocal relationships with their environment (Golubiewski, 2012). As argued by Byrd et al. (2017), this can be compared to 'traditional' infrastructural systems (e.g. transportation or information), where structures that are functionally connected enable flow to occur between nodes. In this context, this particularly refers to water flow facilitated through the development/conservation of riparian areas, at the interface between rivers and land.

The predilection for these characteristics requires to be understood in contexts of implementation. This is particularly crucial where the understanding of complex social-ecological-infrastructural conditions demonstrate current limits to the concept, its planning and implementation, and the need for approaches sensitive to local conditions.

GI in informal settlements

A literature review by Brink et al. (2016) covering 4040 articles on ecosystem-based adaptation found that most studies on the topic are conducted in cities in the northern hemisphere. They also identified a

bias towards Europe, North America and Eastern Asia. Similarly, the concept of 'Green Infrastructure' and its application have predominantly existed in city contexts from the Global North. Its relevance and practical application are still largely misunderstood in a wide range of contexts. Recent research has explored implementation in African, Latin American and South-East Asian cities (e.g. Douglas, 2016; Echavarria et al., 2015; Lindley et al., 2018; Molla, 2015), but important gaps remain in the understanding of how GI and concepts similar to it can be applied in diverse contexts.

To Herslund et al. (2007), GI is not well integrated into planning and governance in African cities because of particular institutional configurations putting barriers to its development. Schäffler and Swilling (2013) argue that ecosystem services approaches are not well integrated into planning and governance of African cities because of a lack of public valuation and legal recognition of green spaces. Maruani and Amit-Cohen (2007) argue that open space management – including for parks and gardens – has traditionally developed in wealthier parts of the city, with a focus on beautification for recreation. The urban greening movements, to which GI is part, follows a trend where only a privileged elite can benefit.

As a result of this trend, little attention has been given to GI implementation in informal settlements to date. This relates to important challenges that exist for the implementation of GI in such contexts, particularly around urban density, questions of informality and land-tenure. Conflicts particularly occur where the protection of ecologically fragile areas involves the removal of families settled there. However, multiple positive connections also exist between informal settlements and urban GI. This starts from a geographical proximity as settlements are often located in ecologically significant and environmentally sensitive parts of the city such as floodplains and wetlands (Adegun, 2017). Through more inclusive processes, we argue GI presents the potential to protect ecological zones while filling service gaps that institutions are struggling to address for these urban dwellers.

There is now a growing body of research exploring synergetic approaches between urban green spaces and greywater treatment or drainage services in vulnerable areas. Parikh et al. (2012) demonstrated the value of nature-sensitive solutions developed according to natural water flow paths to provide drainage services to slums in India. On this aspect, further learning can be drawn from established knowledge on SuDS which has well-expanded in climate change and flood mitigation studies (Gill et al., 2007; Ogie et al., 2019).

Douglas (2010) reviewed cases of green infrastructure providing city-wide floodwater conveyance and storage services, while also provisioning services for informal settlements in sub-Saharan Africa. He argues there is a role to play for GI developed as floodwater management systems to also support urban and peri-urban agriculture practices by making space for cultivated land. The potential of such synergetic actions has been demonstrated in the Kibera settlement of Nairobi in Kenya. In this case, the Non-Governmental Organisation (NGO) Kounkuey Design Initiative (KDI) has supported Kibera communities – whose vulnerability is exacerbated by insecure land tenure – to combine existing agricultural practices with flood control, bank erosion prevention, and organic prevention of waste management (KDI, 2015). Together, they implemented a series of micro-interventions leading to the creation of networked and layered multifunctional GI to make space for water and expand established urban agricultural facilities. The network, being adjacent to the rivers and tributaries of the settlement, supports river remediation (Mulligan et al., 2016).

Exploring the factors and conditions that enable or preclude inclusive and sustainable development of GI is crucial to draw lessons that can benefit similar contexts. In the case of Kibera, the existence of local urban agricultural practices has participated in facilitating the development of a GI network of micro-interventions (Odbert and Mulligan, 2014; cited in Douglas, 2016). Such types of established practices are recognised as opportunities to create momentum for the further development of GI network that benefit entire hydrological systems. Yet, both barriers and enabling conditions that preclude

or facilitate GI development at local scale and enable greater impacts (for example, at the basin and city scales) remain poorly understood, and particularly on the socio-political side.

GI is typically approached as a win-win solution, but fundamentally separates technoscience from social systems. This conceptualisation reflects a dominant policy direction in urban planning that affects the sustainability aspect of GI implementation, which actually requires the combined understanding of planning regimes, governance systems, residents' attitudes and perceptions regarding its impacts, even when it is biophysically viable (Matthews et al., 2015).

A persistent issue regarding GI also refers to its failure in structurally addressing spatial conflicts, and to capture how they are manifested at the local scale for both citizens and ecosystems (di Marino and Lapintie, 2018). In the absence of consideration of social contextual factors, GI development in informal settlements runs the risks of exacerbating local vulnerabilities. As interdependencies occur between the geographically distinct urban landscapes, community identities, and specific practices of active citizen groups across cities (Buijs et al., 2016), we argue that sustainability can only occur if transformation is coordinated at various levels considering socio-ecological-infrastructural systems at the scale at which they exist.

SUSTAINABILITY TRANSITIONS THROUGH THE MULTIPLE-LEVEL PERSPECTIVE

The paper argues that certain forms of institutional GI planning run the risk of (re-)producing local vulnerabilities, similarly to that of traditional urban development strategies that seek the rehabilitation and protection of water systems. This emphasises the need for alternative means that can benefit water systems as well as populations in informal settlements through more inclusive approaches. For this purpose, we analyse the value of sustainability transition theories, of which the Multi-Level Perspective (MLP) is part. Theories of sustainability transitions refer to processes of fundamental change in response to persisting socio-environmental challenges. They have been developed to diagnose social problems that impede the sustainable development of societies constrained by dominant practices and structures (Grin et al., 2011; Avelino et al., 2016).

Geels (2011) highlights that many unsustainable systems exist because of various lock-in mechanisms such as power relations, scale economies, or sunk investments in technologies. Consumer lifestyles may have been adjusted to existing technical systems and also enabled their establishment. These lock-in mechanisms create path dependency and make it difficult to dislodge existing power systems. Sustainability transitions theorists particularly call for attention to politics and legitimisation in transitions, through the conceptualisation of power and social justice. They argue that institutional commitments, shared beliefs, discourses and political lobbying stabilise existing systems and perpetuate injustice (Unruh, 2000). The core analytical puzzle is to understand how innovations emerge under these conditions, and how these can replace, transform or reconfigure existing systems.

The MLP comes from the realm of sustainability transition theories. It has been used across the literature to analyse the conditions in which socio-technical transitions can evolve as a result of the emergence of innovations. It distinguishes itself from other multi-level frameworks in the way it focuses on incremental change, and on actors and specific forms of knowledge that are necessary to have insight into the system change (Sauer et al., 2016). The MLP considers three levels of analysis:

- The *regime* is the level where institutional ruling systems are established. It is composed of networks of actors who are part of established institutions with formal mandates to fulfil societal needs. It operates through rules and practices considered as 'traditional' (e.g. river management practices consisting in building water tunnels);
- The *niche* is where radical innovations and experimentations are developed. They can exist in different contexts, such as in R&D laboratories, community initiatives and grassroots movements (Wolfram, 2017);

- The *landscape* provides the wider environment in which niche and regime dynamics occur. It is the external context that influences interactions between the niche and regime levels, and has been defined in biophysical and social terms, varying from climate change impacts, to political ecologies and cognitive routines (Geels, 2011).

'Multi-level' refers here to micro-meso-macro levels, defined as different degrees of systemic structurations that interact with each other. These levels are considered as *nested systems*, where the micro level (niche) manifests itself dynamically within the meso level (regime), which itself is influenced by socio-political and ecological factors at the macro level (landscape). While the *landscape* and the *regime* represent spheres in which ecological systems exist in relation to institutions, rules and networks, the *niche* level is where alternatives take place. The three levels have different levels of stability, the landscape being the most stable level. A destabilised regime (due to pressure from the landscape and/or from the niche level) opens space for niche innovations to emerge and disturb lock-in mechanisms by providing opportunities for change. Figure 1 provides a schematic representation of transitions elaborated by Geels (2011).

Herslund et al. (2017) have applied the MLP to GI, in sub-Saharan Africa. They theorised the regime as the system of established green space and water management structures with their related actors. The niche is defined as an emergent GI thinking with alternative water management practices. They argue that transitions towards sustainability can take place as 'regime shifts' through:

1. Niche innovations building internal momentum to challenge the regime;
2. Changes at the landscape level exerting pressure on the regime;
3. Destabilisation of the regime creating windows of opportunities for niche alternatives to become regimes.

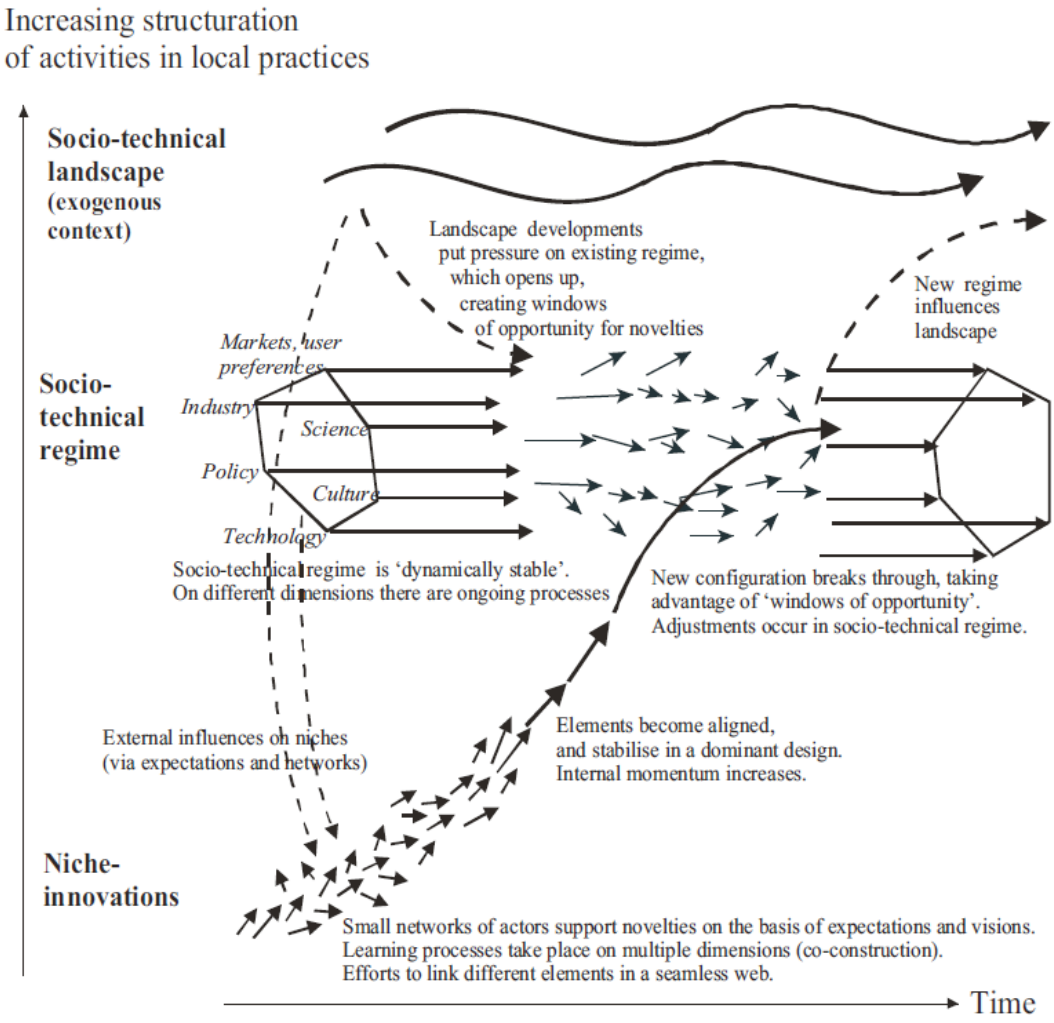
FRAMING THE MULTI-LEVEL PERSPECTIVE FOR GI: SÃO PAULO'S CONTEXT

The MLP framework presented in this part builds on the work of Herslund et al. (2017) who conceptualise the interplay between the formal and informal actors of water management. Our framework specifically aims to analyse the transition from established water management methods, towards alternative water management practices that involve the retainment of green spaces.

The MLP is applied in São Paulo city to provide an example of identification and characterisation of the regime, landscape and niche levels. These are analysed to identify conditions of emergence of innovations at niche level, and how they destabilise the regime. Water management in São Paulo represents persisting socio-environmental challenges. These are reflected in current major gaps in sanitation and drainage. Official figures stipulate that about 50% of the city's sewage is treated by the municipality, but the actual percentage of treated wastewater in the city is known as being much below (Go Associados, 2018). Besides, major flood issues affect the entire population each year, which reflect significant drainage challenges often aggravated by the presence of solid waste in the streets. Various factors have fostered the population's understanding of the link between the degradation of green cover and water quality and flood issues in the city over the past few years (SMDU, 2012).

We identify that an MLP analysis can help a structural deconstruction of issues by examining them at different socio-ecological-infrastructural system levels. Such an analysis should aim at differentiating capacities, resources, perceptions and everyday experiences in the regime from those of the niche. By aiming to emphasise disconnections between such parameters at different levels, the MLP thereby explores opportunities for regime destabilisation which can make space for niche innovations.

Figure 1. Geels' multi-level perspective on transitions (2011).



Water management strategies in the regime

The regime is framed here as the realm of institutions and formal networks (governmental authorities and organisations they collaborate with) and rules (policies and regulations) that establish the way water resources are managed in the city. These govern land and water bodies, from the perspective of service provision in water, sanitation and drainage, in parallel to biodiversity and natural resource protection. For São Paulo, this notably relates to the range of governmental entities exerting authority at federal, watershed, state, and municipal levels and the legally binding instruments they articulate.

The government's traditional investment in grey infrastructure (for example, large-scale dams for hydropower generation) is an example of mechanism that has participated in the construction of today's socio-technical conditions in which water and green space management systems are locked. The country's richness in water ecosystems has continuously supported the establishment of such systems focused on production to respond to growing demand. Nowadays, the evident pressure on water resources is reflected in the poor quality of surface water and groundwater systems, as well as in the impacts of climate events. The 2014/15 droughts particularly evidenced the limits of current water governance systems, from both the social and environmental perspectives. These have led to attempts

by the government to move towards new forms of strategies for the management of water systems (Silva and Grostein, 2008; Duarte et al., 2010; Instituto de Estudos Avançados, 2018).

Today's approaches in water management increasingly include the restoration, conservation or development of green areas which support water resources. Relevant legally binding water conservation and green area development plans include the federal law 12.651/12 (Florestal Code) for Permanent Preservation Areas (PPAs) which established a minimum width of river bank protection of 30 meters (Sepe et al., 2014). However, in current dense city contexts such as São Paulo, the execution of this federal law enters in conflict with other land-use purposes as established in municipal laws, including that of housing, and thereby renders its application prohibitive. In certain parts of the city, this can mean drastic changes in the urban landscape due to the requirement to relocate populations settled along rivers' margins.

Further challenges in the regime are also reflected in the context of *mananciais*. These refer to the surface water and groundwater source areas exploited for drinking water distribution, which are particularly widespread in the southern part of the city. These areas require special legislation for protection. Since the 1970s, the State government has exerted efforts in preserving them by reinforcing regulations, notably through Law nº 9.866/97 (Duarte et al., 2010). However, important tensions have emerged due to the expansion of informal settlements in these areas sought for ecological preservation. Official documents refer to the *mananciais* being "negatively affected by various urban phenomena (slums, irregular settlements, land invasions, etc)" (Governo do Estado de São Paulo, 2007, p. 1). Key issues in São Paulo's urban development interventions highlight these conflicts of socio-ecological-infrastructures systems over land.

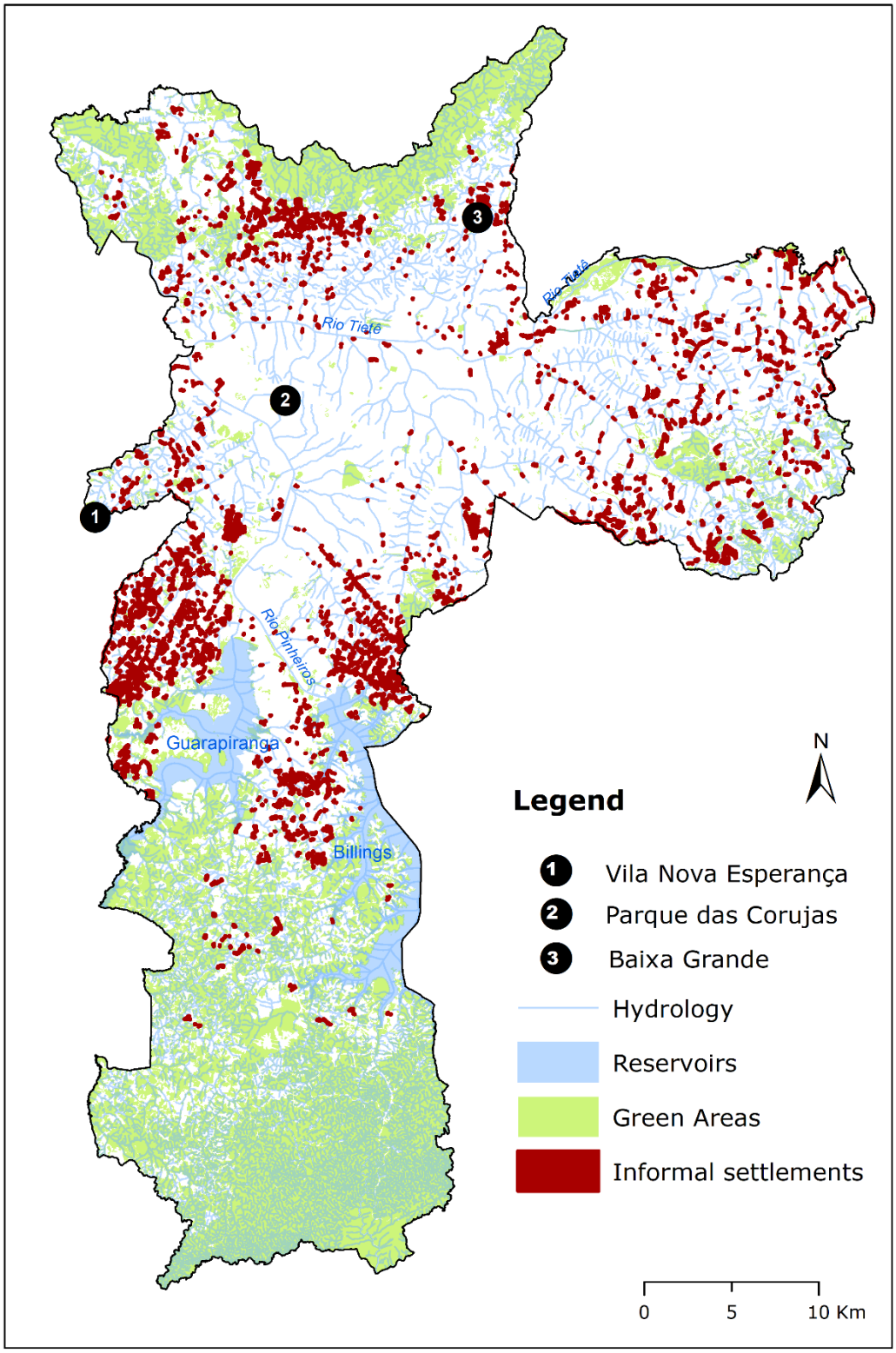
Other initiatives in the regime have deployed efforts to develop green infrastructure-type of water management systems in the city. The Corujas Park ('Owl Park'), has consisted in the development of a large green area facilitating rainwater infiltration and drainage, combined with the development of a recreational area that today includes a community garden (LABVERDE, 2012). Developed in a high-income area, it is one of the rare water rehabilitation interventions recognised as green infrastructure in the city. Figure 3 shows the localisation of the project along with the geographies of hydrological bodies, green areas (here including legally protected zones and existing municipal parks) and informal settlements in the city. An important question remains regarding the planning and implementation of this type of interventions in challenging contexts characterised by high urban density and where other planning priorities remain to be addressed.

Many similar projects are planned in various parts of São Paulo. These include linear parks, introduced as part of slum upgrading projects. Along the Água Podre River in the West zone of São Paulo, families were evicted by the local government in prevision of such a project. Yet, for a majority of these projects including that of Água Podre, the plan has only been partially implemented, or never been implemented.

Pressure from the landscape

The landscape represents the wider environment, or the "technical and material backdrop" that influences the regime functions (Geels, 2011: 28). This includes political ideologies, societal values and macro-economic patterns. While the theorisation of this level has caused disagreements, we propose to define the landscape along both notions of shocks and stresses as framed by van Driel and Schot (2005; cited in Geels, 2011). Here, we refer to climate change impacts on water resources (both short and long-term impacts), as well as demographical trends that drive urban development patterns.

Figure 2. Informal settlements, green areas and examples of green infrastructure projects in São Paulo (Source: Barbara Pozzan dos Santos Duarte and Loan Diep).



Regarding climate change impacts on water resources, the São Paulo water crises from 2014 and 2015 represent examples of shock that resulted in in the adoption of critical measures in water management systems (Campari and Barrêto, 2014; Arup, 2016). For example, to meet the supply gap, the São Paulo state utility SABESP pumped the 'dead water volume' of reserves that normally remain under legal protection. Through agreement between different government levels, large-scale infrastructural arrangements were made to connect water reservoirs together and thereby create a redundant system to balance sources of supply to the city.

The crises also resulted in increased awareness around longer-term action in water ecosystems management through the conservation and development of green areas that support hydrological resources. Such awareness was not limited to the regime side, but also led to an increased consciousness among the population (Jacobi et al., 2015). As such, the landscape has not only exerted pressure and destablished the regime by testing its adaptive capacity, but has also fostered the emergence of niche initiatives.

Analysing the landscape also provides insight into the way political values, societal values and economic patterns have influenced space management for urban development systems in the regime, including for informal settlements. Furthermore, we identify international systems as being part of the landscape, including for knowledge production, political pressure, and economic agreements, whether they have a direct or indirect influence on both the regime and the niche. This therefore includes the manner through which international research and strategies impacts national plans for water management, for example through United Nations guidelines (see UNEP, 2014; Hansen et al., 2017).

A determinant example of cultural value that participates in the construction of the landscape is that of perceptions towards favelas and their residents in the city of São Paulo. On the one hand, the strong association made between favelas and 'invasion', 'pollution' and 'lack of education' is identified as a driver of exclusion of informal settlements. On the other, an emerging societal discourse around interventions for and with residents of favelas puts pressure on regime systems that exclude them from institutional structures, including from green infrastructure initiatives. Both aspects of this cultural valuation can be defined as push and pull factors between the regime and the niche.

Alternatives in the niche

The niche represents the realm in which alternatives to water management and green space development through GI-type of practices emerge. The GI practices explored here refer to sanitation practices for water treatment and drainage through plant-based systems. We particularly explored innovations driven and implemented by civil society actors outside the regime. These referred to the range of existing initiatives that seek to actively plan and implement practices aligning with the concept of GI, and this in an inclusive manner. As such, participation is important in order to consider work with local flows of resources, needs, motivations and aspirations.

In the context of informal settlements of São Paulo, we identify movements across the city that seek the development of green areas. Examples of initiatives discussed here are also represented on Figure 3. These initiatives generally serve multiple purposes, typically around education, recreation, and financial autonomy on the one hand, and water infiltration, water treatment and water reuse on the other. Many activists work on a voluntary basis to develop projects using a discourse of sensibilisation to the population, particularly in schools which provide a platform that is easily accessible to this type of interventions.

For example, the collective 'do Estradão' in Serra Pelada (Baixa Grande), in the North zone of the city, has been transforming an abandoned space used as an informal landfill zone located between a favela and a school into a space for permaculture experiences since 2015. Along the various varieties of plants being cultivated with low water-intensive systems, the collective has also created an infiltration zone with a simple nature-based design. It is based on cardboard, fabrics, banana plants, *taioba* (or 'arrowleaf

elephant ear') to enable water of a *nascente* (water source) located in the school to flow to the closest river without inundating the space. The space now belongs to the everyday life of residents as it serves as a pathway between the favela and the centre of the neighbourhood, and is used by children who live in the community and frequent the school, both for recreational purposes, and for experimentation.

In the West Zone of São Paulo, the community of the Vila Nova Esperança has developed initiatives to protect and develop green areas in their region. These initiatives emerged at the same time the community became threatened of eviction due to its location in an ecologically protected zone and its proximity to a *manancial* zone. The threat has been emphasised by authorities through a political discourse around the argument that the community pollutes the area. In response to this, the inhabitants launched a solid waste management initiative along with a peri-urban agricultural zone within the settlement in 2013. Inhabitants of the favela have access to medicinal plants from the community garden where they cultivate vegetables, fruits and herbs. The range of initiatives has expanded over the years and gained attention from NGOs and the public. No further eviction threats have been received by the community. Further water management initiatives are developing, including through a collaboration with the University of São Paulo to construct a plant-based treatment system for the sewage of 40 local households.

Figure 3. Permaculture methods applied in the settlements of Serra Pelada (Baixa Grande) (left) and Vila Nova Esperança (right) (Credits: Loan Diep).

DISCUSSION

An ongoing sustainability transition?

In Brazil, the term 'green infrastructure' (*infraestrutura verde)* has mostly existed in research contexts, with academic studies supporting its establishment (see for example Lima and Schenk, 2018). At government level, while the term is not predominantly reused in legal instruments, various policy documents or institutional frameworks have introduced urban development strategies that coincide with GI and/or Low-Impact Developments which are based on comparable principles. For example, Hannes (2015) identified the adoption of the concepts of multifunctional spaces and network of green areas in the 2014 municipal master plan of São Paulo.

As shown with the examples of law enforcement for water management from an established regime that applies traditional top-down planning, tensions emerge between social and ecological systems at multiple scales. Projects established by the regime demonstrate a disconnection between various government plans and activities that take place in the niche. Furthermore, grey infrastructure type of water management remains largely dominant in the regime. Various government efforts to protect or

expand green areas in parts of the city poorly perform in terms of hydrological resource protection, thereby demonstrating that the green space management regime may remain concerned with beautification as opposed to ecological objectives. So-called green infrastructure runs the risk of perpetuating similar socio-ecological problems as those developed by traditional water governance and management systems. As such, the question of an ongoing transition through technical change triggered by the adoption of GI implementation methods requires further critical analysis.

The emergence of initiatives in the niche, within and in response to the regime and landscape, can be explained by different factors. In the case of Vila Nova Esperança, exposure to risks of eviction has been a key driver to community gathering. More generally, community organisation and stewardship is a crucial ingredient without which projects run the risks of fading over time (Buijs et al., 2016). Sociocultural factors related to local knowledge stimulated around the cultivation of plants and further green space development projects have also participated in the emergence of niche alternatives. The alternatives have demonstrated forms of sustainability in the way they are rooted in people's everyday activities. Conditions for innovations are therefore taking place in a context presenting characteristics of flexibility in an informal structure (as opposed to a context of formal planning), but also of stability in the way they are anchored in local routines.

The development of such initiatives can be seen as a direct response to the regime's failure in adopting context-sensitive approaches. For example, the case of Vila Nova Esperança represents a case of regime destabilisation where the green initiatives demonstrated the flaws of the pollution discourse used by the regime (and perpetuated through the landscape) against inhabitants of the settlement. Most importantly, the analysis of the niche alternatives in comparison to regime interventions emphasise the idea that sustainability transitions do not rely solely on technical change, but fundamentally occur in the governance aspect of the way interventions take place to address societal challenges.

The value of the multi-level perspective

MLP analyses highlight the disconnection between urban development practices and lived experiences on the ground. Furthermore, they can provide significant insight into the identification of opportunities for sustainable socio-technical transition. This helps highlight current instabilities in the regime, including through pressure from the landscape requiring changes in the way ecosystems are governed. It also highlights instabilities caused by pressure from the niche (but also resistance to it), which calls for changes in the way urban development occurs. This particularly emphasises the way in which power is not concentrated at a particular level, but that different dimensions of power are in fact dispersed among actors and across levels (Avelino et al., 2016). Changes therefore require to break patterns of exclusion in which different actors are locked at these different levels.

Several elements of the framework require particular attention when undertaking such an analysis. Discussions around the micro-meso-macro levels have shown limitations in the way actors are categorised at each level. Characterising the regime with institutions (and mainly with governmental actors), and the niche with 'communities', limits the framework in the way it can capture the complex dynamics that exist within and between these groups of actors. Further definitions of formality and informality are also required to better characterise conditions for regime destabilisation. This is particularly relevant in the context of favelas in São Paulo of which the social characteristics differ from one another.

Similarly, a key critique to MLP relates to its potential bias towards bottom-up change models. The conceptualisation of power and politics in sustainability transition theories requires to move beyond the 'niche-regime dichotomy' ("small and agile with big and strong"), and the way innovation is often represented in a dialectic manner (Avelino et al., 2016: 560). We seek to overcome these biases by demonstrating the non-homogeneity of each level. This will occur through the deconstruction of social

and ecological systems within each of these levels to highlight trade-offs in urban development strategies.

Another limitation lies in the hierarchal aspects of the three levels. While these levels refer to different degrees of stability, these do not necessarily exist in a hierarchal manner. Geels emphasises the limits of the nested aspects of these levels as most niches do not emerge *within* regimes, but often *outside* them "although niche actors are usually aware of regime structures" (Geels, 2011: 37). Similar arguments can be made for the socio-technical landscape being external to the regimes and niches, and therefore their relations are not necessarily hierarchical. However, we recognise their dynamic co-influences occur in snowball effects and that framing the levels as such is helpful to 'travel' from the local up to the international scale and establish links between them.

Finally, to overcome the risk of approaching the landscape level as a "residual analytical category", it requires to be conceptualised in a dynamic way (Geels, 2011: 36). Along these lines, this level requires conceptualisation as both an enabling and a disabling environment. Where conceptualised through climate change risks and related adaptation strategies, the landscape helps linking actions at different institutional levels. An enabling factor may relate to the mobilisation of international funding, whereas a disabling factor relates to the mismatching aspect of the conditions attached to their use with the local level (Colenbrander et al., 2017). This represents a particularly important blocking issue in informal settlements where climate impacts are typically the greatest. Policies and strategies, designs and investments, all require to consider these areas as integral parts of the city in order to enable the sustainable development of its web.

CONCLUSION

If GI presents potential to lead to societal sustainability transitions that can benefit both social and ecological systems, further characterisation of the concept is required. The article highlights the relevance of interdisciplinary perspective to evaluate GI interventions, particularly to better bridge technical with socio-political factors. Understanding the range of conditions which determine the materialisation of the concept helps identify the range of barriers, risks and opportunities that exist but which are commonly overlooked. In this aspect, the MLP can greatly support such analyses.

MLP structurally helps capture power relations and interdependencies embedded at the macro-meso-micro levels, and reproduced in infrastructural designs of interventions and delivery processes to identify opportunities for inclusive implementation of GI. Following the characterisation of the framework with the case of São Paulo discussed above, future work includes operationalisation of the framework through a combination of participatory research with local communities in informal settlements, and consultation with local and regional government stakeholders. This can support the further definition of boundaries of the regime, the niche and the landscape.

To explore opportunities for coalitions between the niche and regime in context, there is also a need to better understand socio-ecological tensions. This requires to explore the local impacts of current top-down water management systems. In parallel, everyday practices around the use of green spaces need to be further understood. That includes the identification of current coping practices occurring outside the regime at local level, for example in relation to inundations and water-stress events. This helps align currently disconnected niche initiatives with regime interventions. Furthermore, the analysis of participatory decision-making for regime interventions in informal settlements is particularly important to enhance learning on local aspirations towards GI to facilitate planning and implementation in the short-term, and foster stewardship in the longer-term. These analyses will highlight conditions for transitions and explore the potential use of GI solutions to improve living conditions for residents in informal settlements and other resource-challenged settings.

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