Environmental Science and Policy 99 (2019) 160–168

Contents lists available at ScienceDirect

Environmental Science and Policy

journal homepage: www.elsevier.com/locate/envsci

Making 'green' fit in a 'grey' accounting system: The institutional knowledge system challenges of valuing urban nature as infrastructural assets

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ARTICLE INFO

Keywords:
Green infrastructure
Asset management
SETS
Knowledge systems
GASB
SASB
Standardization
Standards

ABSTRACT

Nature is increasingly enrolled as a functional component of infrastructure in cities as municipal governments attempt to cost-effectively replace and repair deteriorating engineered infrastructures. Green infrastructure (GI) is a popular incarnation of this enrollment, most often defined in the United States (US) as the use of vegetated land (e.g. street-trees, bioswales, parks) to provide stormwater management services. However, GI is far from mainstream. While many municipalities cite technical performance uncertainty as a primary reason for this lag, institutional challenges of knowledge system integration also create road-blocks to GI management.

In this paper, I argue that financial asset management (AM) standards are an important, but obscured, institutional barrier to the mainstreaming of GI in the US. I use Knowledge Systems Analysis to illuminate the institutional tensions that emerge from attempting to fit nature into existing AM practices. Primarily, tensions stem from the inability to "book" natural components of GI (such as trees, soils, vegetation) as assets as they are not recognized by US financial accounting rules and standards; this has encouraged a proliferation of highly engineered GI that contain human-made components at the expense of more ecological GI that do not contain human-made components. I first review the use of corporate AM practices in North American municipalities, and outline the general motivations for including urban nature in AM. I then zoom in on a case study in Portland, Oregon where a 2016 effort to create a city-wide Green Asset Plan encountered road-blocks that reflect the wider national knowledge system challenges surrounding making nature into infrastructure. In particular, different valuation methods (i.e. the use of replacement value vs service value) are at the heart of the conflict between accounting and ecological knowledge systems. I conclude with a discussion of the political implications of GI's increasing standardization to fit grey infrastructure knowledge systems more broadly and the ways that this movement leads to a depoliticization of nature.

1. Introduction

1.1. The rise and 'stall' of municipal green infrastructure

Over the past 20 years, green infrastructure (GI) development has increased in cities in the United States (US) that are working to cheaply and sustainably address stormwater infrastructure deterioration, overcapacity, and inefficiency (WERF, 2009; EPA, 2015). Typically defined in the US[1] as the use of vegetated land (e.g. street trees, bioswales, parks) to provide stormwater management services (EPA, 2015), GI enrolls nature (e.g. plants, soils) directly as a functional component of infrastructure facilities. GI is increasingly preferred as a replacement or complement to pipes, pumps, and other human-built components of traditional engineered systems (often referred to as 'grey' infrastructure). In contrast to single-service grey infrastructure facilities, GI has been shown to provide a number of co-benefits (e.g. improved air quality, attenuation of urban heat islands) along with its designed utility function, and is often more cost-effective than grey options (American Rivers et al., 2012).

However, effectively implementing GI requires valuing and maintaining nature comparably to the ways we value and maintain human-built infrastructure. Traditionally, this is done through financial asset management (AM), which is governed by accounting standards. Accounting standards are determined nationally and dictate what can be "booked" as an asset (i.e. what property, buildings, and/or supplies a company can legally record on the ledger to express their net worth) among other financial reporting needs. Accounting standards protect investors and businesses by removing (as much as possible) the ability of a company to falsely inflate their worth. Currently, the living, biological components of GI are not encompassed by these standards

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[1] See Mell (2013) for a discussion of contested conceptualizations of green infrastructure globally.

https://doi.org/10.1016/j.envsci.2019.05.023
Received 1 October 2018; Received in revised form 21 May 2019; Accepted 23 May 2019
Available online 24 June 2019

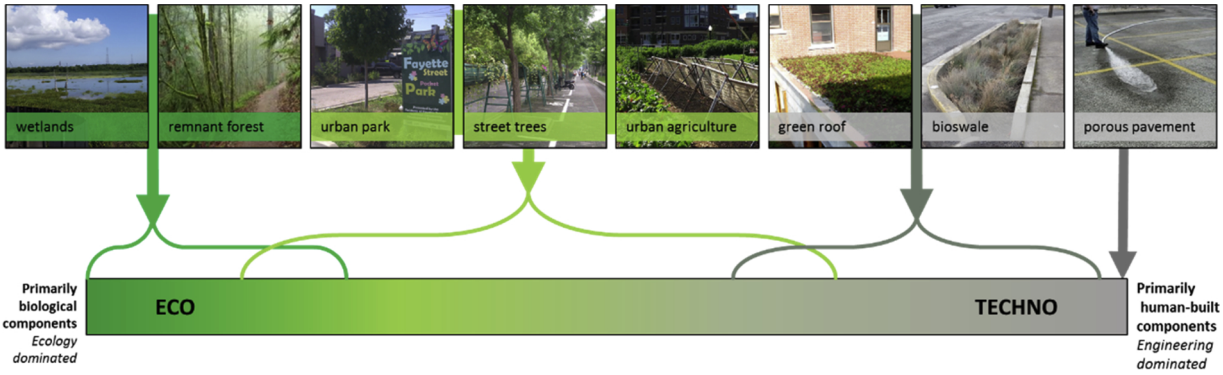

Fig. 1. The eco-techno spectrum organizes GI facilities by the proportion of the facility that consists of living, natural components vs human-made, technological components. Photo Credits: Marissa Matsler (wetlands, urban park, street trees, bioswale); City of Portland (remnant forest, green roof); Create Commons (urban agriculture); Milwaukee Metropolitan Sewerage District (porous pavement).

leaving them with zero asset value. This conflicts with ecological assessments of GI which value multiple ecosystem services.

In order to accurately value GI, the knowledge systems that form accounting standards and ecological assessments must be reconciled. A *knowledge system* (KS) is defined here as the system of norms, protocols, and practices that produce and vet knowledge claims used in decision-making (Miller and Munoz-Erickson, 2018). Because GI facilities are hybrids, consisting of both natural and human-made components, GI decision-making requires the blending of knowledge norms, protocols, and practices from both the discipline of ecology and engineering. Scholars organize GI hybridity along continuums to acknowledge that clear lines do not exist between 'grey' and 'green' facilities within current definitions of GI (Bell et al., 2018; Royal Society (Great Britain), 2014; Mell, 2013). Here, the ecological-technological spectrum – or *eco-techno spectrum* for short – is used to organize the different types of facilities and greenspaces that are recognized as GI across different organizations (Fig. 1).

On the 'eco' end of the eco-techno spectrum, ecological knowledge claims tend to dominate, while the 'techno' end is governed by engineering knowledge claims. These knowledge claims are created by two – often incommensurate – disciplinary knowledge systems, presenting challenges to management of GI as a single infrastructural system. Municipal departments responsible for designing, implementing, and maintaining GI networks in cities across the US are negotiating these challenges – in particular, the understanding of asset value as a replacement cost (in accounting terms, which is aligned with engineering KSes) versus the value of its service (in ecological terms). Importantly, the nature-technology hybridity of GI also intersects with the tensions between understanding nature as infrastructure versus a luxury or amenity. For example, GI on the 'eco' end of the spectrum is usually not recognized as infrastructure at all, due to its lack of characteristics that are knowable to the engineering KS.

Of particular interest here, is the lack of fit of the natural components of GI with AM practices. Overseen by engineers and, therefore, built up in-line with engineering KSes, infrastructure AM practices are increasingly used by municipal governments to efficiently re-invest in neglected infrastructural systems (Leighton et al., 2016). However, GI does not benefit from this kind of investment or planning for maintenance and repair because, as mentioned above, GI facilities are not recognized officially as assets by accounting standards. This means that while individual municipal departments may track and report facilities like parks as assets internally, *city-wide* accounting rules and standards only capture human-built infrastructure (e.g. pipes, culverts, playgrounds, etc.), leaving out all-natural facilities (e.g. trees, grassy swales, wetlands, etc.).

My dissertation research of GI implementation in Portland, OR identified an emerging initiative to integrate GI into city-wide AM through the compilation of a draft Green Asset Report across multiple city departments. This led to the research questions explored in this paper: Why and how is GI being integrated into AM processes in Portland? What challenges does this process face? Why is green AM generally not yet mainstream? I also track the ways that nature is known as infrastructure vs a luxury or amenity to better understand how this influences the integration of GI into AM, as the grey literature points to this as an important distinction (e.g. NRPA, 2010).

While the distinction between human-built and natural components may seem to be merely a semantic disagreement, it can have real-world consequences for GI management. For example, in 2014, a lawsuit challenged Portland's Bureau of Environmental Services' (BES) GI program. The lawsuit called bioswales – of which more than 2000 had been built throughout the city – an "unauthorized expenditure" for the sewer utility (Law, 2014). This invigorated a legal discussion around the legitimacy of using nature as infrastructure, as a newspaper article at the time points out:

> In a citywide debate on the proper role of the city water and sewer utilities, it's a good time to ask: Are these bioswales and related Green Streets projects a good investment for the city's utility ratepayers? Or are they a nonessential frill pushed by green do-gooders? (Law, 2014)

> Essentially, ratepayers argued that GI development was outside a sewer utility's mission and insisted BES focus funds on 'real' sewer projects like pipes:

> DiLorenzo says there's been "mission creep" at the city Bureau of Environmental Services, supported by green activists. "They believe this isn't a sewer agency at all anymore," he says… (Law, 2014).

While the lawsuit was ultimately overturned, it was a "wake-up call" to municipal staff. GI is an integral part of BES's stormwater and wastewater management system, as well as a key component of their federally mandated combined sewer overflow (CSO) plan. However, plaintiffs did not regard GI as such; instead of infrastructural facilities, ratepayers saw general greening and greenspaces, something that was a luxury or economic development tactic at best. This lawsuit therefore highlights the importance of understanding the epistemological differences inherent in knowing GI in different communities in the city. KS analysis is therefore particularly useful for looking at the emergence of green AM, allowing for the examination of embedded values and epistemologies in institutional practices. Ideally, KS analysis will point to areas of congruence between otherwise conflicting KSes, helping in the redesign of existing municipal KSes to address ongoing challenges, like the mismatch the 2014 lawsuit highlights.

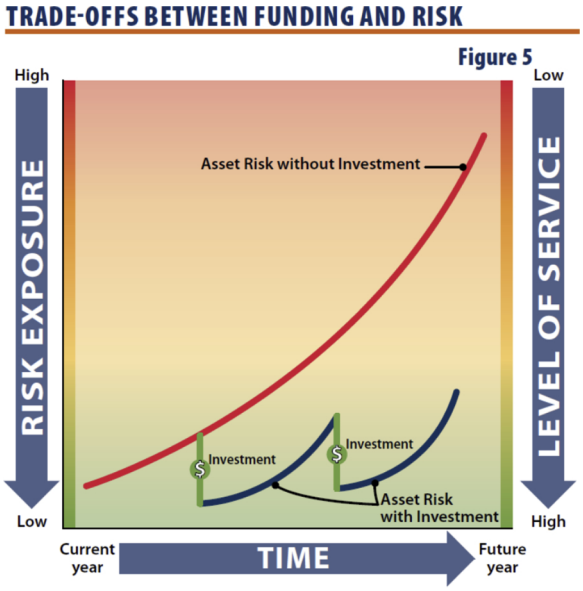

Fig. 2. Relationship between risk, level of service, and investment through time of infrastructural assets (from Portland's annual city-wide asset report 2015).

1.2. The asset management solution to the infrastructure maintenance problem?

Asset management (AM) techniques provide infrastructure managers with a prioritization process for facility repair and maintenance. The emergence of standardized AM practices in US municipalities began in earnest in the 1980s (Leighton et al., 2016). Public infrastructure across North America was in disrepair and a focus on new development at the expense of existing development exacerbated the problem (Vanier and Danylo, 1998). Municipal managers borrowed AM techniques and standards from private industry to systematically prioritize the maintenance of infrastructural networks.

Municipal AM can be simply defined as "a set of practices and methods for delivering desired services to residents and businesses, at the lowest life cycle cost (including environmental and social costs), while managing risk to an acceptable level" (McGraw-Hill Construction, 2013). Fig. 2 displays the relationship between services, risks, and maintenance as conceptualized by asset managers. There are four common steps used to assess this relationship: 1) inventory assets, 2) assess the condition of inventoried assets, 3) assess the value of inventoried assets, 4) calculate the funding gap between budgeted funds and funds needed to maintain assets at defined levels of service (Leighton et al., 2016).

How does this technical process intersect with the values and epistemologies explored in KSes? While the AM process sounds objective and straightforward, each step has embedded unspoken but powerful choices about what matters and what doesn't in the realm of infrastructure. For example, in step 1, what counts as an asset to be included in an inventory? This decision is based on a very specific worldview which originated in the context of for-profit business optimization (Leighton et al., 2016). One of the consequences of this is a focus on the resale or replacement value of an asset rather than its service or use value. Replacement value here is not to be confused with the cost of replacing a service provided by nature with a grey infrastructure proxy (i.e. it would cost New York City nearly $10 billion to build a treatment plant to provide the same amount of clean water as $1.5 billion in watershed conservation currently does (Ecosystem Service Marketplace, 2006)). Instead, replacement value in the case of AM is the cost to replace an asset with the same physical asset (see Table 1 for an example of replacement values from Portland). Service value on the other hand refers to the benefits people receive from the use of a physical asset, for example the health benefits of access to clean water provided by pipes and pumps, and is not recorded on the accounting ledger.

Additionally, in GI management, the protocols and practices (i.e. KSes) involved in inventory and condition assessment of nature as an asset differs substantially between departments and institutions. For example, a parks and recreation department and a sewer utility have different mission statements and public mandates meaning that legally they must focus on department-specific services and cannot spend funds on services outside their mandate (as highlighted by the Portland lawsuit described above). Additionally, established financial accounting KSes that dictate asset classes are well-calibrated to human-built technologies, leading GI facilities that include more human-built components (i.e. green roofs, bioswales) to more comfortably fit in existing AM procedures than those consisting of only natural components (i.e. forest patches, riparian areas). This means that there is a focus on facilities on the 'techno' end of the eco-techno spectrum and facilities on the 'eco' end are left out (see Fig. 1 for example facility types).

AM techniques provide infrastructure managers with a prioritization process for allocating maintenance funds. Therefore, we begin to see that these seemingly mundane processes are actually increasingly important leverage points (Meadows, 1999) for municipal staff to legitimate the claim that increased investment in GI maintenance activities is both needed and efficient. For example, a recent survey done of municipal water utilities in the US found that "the ability to explain and defend budgets and investments is the benefit experienced by the largest percentage of those doing…asset management practices" (McGraw-Hill Construction, 2013). In short, by bringing attention to, quantifying, and prioritizing the different risks of infrastructure failure city-wide (as shown in Fig. 2), AM techniques play a pivotal role in guiding long-term investments in municipal infrastructure in the US. A move to explicitly fold GI into AM, by categorizing and measuring facilities as 'green assets', is expected to similarly improve GI maintenance investment patterns. However, when considering the KS challenges this folding presents, it is not surprising that efforts to do so have stalled. Next, I review the knowledge tensions surrounding the value of nature in cities generally and describe current attempts to reconcile these issues nationally and globally, before zooming in on Portland as a local-level example of these dynamics.

2. The value of urban nature: tensions & movements

In an era of climate change and crumbling infrastructure, city staff mandated to provide and maintain urban greenspaces increasingly ask "what is the value of urban nature?" Municipal budgets are notoriously tight, and departments responsible for greenspaces (e.g. parks and recreation departments) are usually funded more sparsely through general funds than utility departments which are funded more reliably by ratepayers. In an attempt to procure much-needed funding for the operations and maintenance of greenspaces, practitioners and researchers argue that the value of nature in and around cities must be more deliberately calculated and communicated to both city decision-makers and the public (Boyd and Banzhaf, 2007). One way to do this is to recognize the value of nature by officially putting it on the accounting ledger as an asset (NRPA, 2010). However, this immediately encounters conceptual difficulties.

To accomplish the task of "booking" nature on the financial ledger using existing accounting practices, the current understanding of the role of urban nature must change. Essentially, urban nature must be understood as a service provider with functions and benefits valued at the same level as other urban infrastructural systems (e.g. the electric power grid). Traditionally, this understanding has not been embraced. Even when parks were advocated by powerful visionaries like Fredrick Law Olmsted, greenspace was primarily considered a philanthropic gift to the poor (Eisenman, 2013; Melosi, 2008). However, this traditional understanding of parks and other urban nature is changing in some

Table 1
An example of major asset classes from Portland's 2016 Citywide Asset Report. (Green stormwater assets separated out as such for first time in 2016 report.).

Table 3. Environmental Services Replacement Values for Major Asset Classes

Asset Class	Value (in billions)	Description
Combined sewers	$3.8	892 miles combined sewer that carry both stormwater and sanitary waste, 667 miles of sewer laterals (owned in the right of way)
Combined sewer tunnels	$1.3	13 miles of large-diameter combined sewer tunnels
Sanitary sewers	$3.3	1,001 miles separated sanitary sewers
Wastewater treatment systems	$2.2	2 wastewater treatment plants with over 8,820 major assets 99 pump stations (including 82 owned by BES, 17 maintained by BES) with over 6,134 assets
Stormwater system – grey assets	$2.0	368 miles of storm pipes, 75 miles of culverts, 327 trash racks, 8,624 sumps, 6,839 sedimentation manholes, and 150 manufactured stormwater treatment devices
Stormwater system – green assets	$0.2	2,064 green street planters, 118 treatment ponds, 140 swales, 9 wetlands, 127 ecoroofs, 183 parcels of natural areas, and 3,874 ditches

circles. For example, the National Recreation and Parks Association (NRPA) asserts that parks and recreation "are essential public services" (NRPA, 2010). In a 2010 report, they use metrics that fit well with engineering valuation techniques (for example, "trees in cities save $400 billion in storm water retention facility costs" (p. 1)) and that resonate with politicians (for example, "a 25 percent increase of residents who exercise at least three times per week" (p. 2)). This is an example of KS alignment. By recognizing and validating urban nature as a service provider, greenspaces can be made explicitly into infrastructure. This has important consequences for the management of urban nature, most notably creating financially- and policy-binding commitments to investment in its design, implementation, and maintenance.

An influential concept in this arena is ecosystem services, simply defined as the benefits humans receive from nature (Millennium Ecosystem Assessment, 2005). Some scientists and politicians hope that the ecosystem services framework will aid in increasing land conservation, preservation, and restoration efforts by quantifying the benefits that humans receive from nature for use in policy-making (National Ecosystem Services Partnership, 2014); others hope that classification of benefits will allow previously unmeasured services to be monetized giving nature equal footing in political debates around ecologically degrading practices (Costanza et al., 1997) or opening up untapped economic markets ("Willamette Partnership", 2014). In other words, the ecosystem services framework attempts to translate ecological knowledge claims into knowledge claims that are credible and actionable within the existing economic KSes dominating development in the world today.

Despite optimism around the ecosystem services concept, actual on-the-ground valuation has proved difficult (Norgaard, 2010; Chan et al., 2012) and fraught with ethical conundrums (Vucetich et al., 2015; Luck et al., 2012). For example, Robertson et al. (2014) find that the practice of "stacking" ecosystem services – meaning multiple different service credits can be sold from a single site – has the unintended consequence of net loss in ecosystem services from an ecological KS view, even though the economic KS is satisfied. Stacking highlights the challenge of translating ecological knowledge claims regarding ecosystem structure and function into financial knowledge claims about benefits and services.

A second movement approaches this issue from the opposite direction; its advocates attempt to widen the financial KS to accept ecological knowledge claims more directly. The Sustainable Accounting Standards Board (SASB) began in 2011 to create a sustainability reporting framework for corporations (Lydenberg et al., 2010). SASB creates the missing standards for private companies to book their sustainability practices so that they can be more competitive to investors who increasingly care about 'being green' (Cowan, 2017). SASB represents the faction of the financial sector, then, that is actively working to adjust its KS to incorporate ecological knowledge claims.

This movement to integrate KSes also faces challenges. SASB remains marginal in the financial world and faces competition from other reporting methods (Leinaweaver, 2015; D'Aquila, 2018). Regardless of push-back, the sustainability movement has permeated private development activities in many ways. This has necessitated the integration of ecological and financial KSes to translate and legitimate knowledge claims for use in decision-making. Both ecosystem services and SASB remain on the fringes of the existing, powerful KSes of mainstream institutions; but, both create spaces for discussion and potential KS innovation at the local municipal level.

3. Case study

3.1. Asset management and green infrastructure in Portland

There are two distinct levels of municipal AM within Portland, Oregon that are relevant to GI: bureau-specific and city-wide. First, each bureau has a dedicated staff that work to inventory, assess, and value infrastructure assets held by that bureau. Because each bureau has different kinds of infrastructure (i.e. pipes, roads, parks, culverts, rec centers, street trees), they each have bureau-specific ways of defining, measuring, and valuing assets. Software has become an important tool in this space and bureaus use these packages to enter inventory and condition data on as many assets as they can afford to assess. In Portland, the software packages themselves differ between departments, further complicating integration.

Second, a city-wide AM group (called the CAMG) compiles relevant reports from each bureau and reports annually to city council with recommendations for prioritization of maintenance and repair for the coming year, as well as the allocation of a special fund for departments with high-risk deferred maintenance. This city-wide AM process began over 20 years ago in Portland. As in other cities, deteriorating infrastructure was an initial driver and AM created a process for allocating funds more efficiently (City Asset Managers Group (CAMG), 2015). This city-wide process is led by certified accountants and is subject to rigorous national accounting standards for reporting to investors.

While city-wide AM of infrastructure has continued, GI facilities

Table 2
Competing knowledge claims, norms, and protocols from ecological vs accounting KSes.

Ecological Knowledge System	Accounting Knowledge System
Definition of 'asset'	
SERVICE VALUE: The value of nature lies in the benefits and services humans receive from its functions	REPLACEMENT COST: The value of an asset is the cost to replace the physical structure of the asset with comparable materials
Assets are just things with a dollar value attached to them.	An asset is something that has a value in the market (i.e. it can be sold).
Measurement	
Limited/unsatisfying metrics to measure the value of nature in dollars to put on a ledger.	No standards exist to allow nature to count as an asset on the books.
Ecosystem components (i.e. vegetation) provide more services through time as they mature; appreciation is variable depending on environmental factors.	An asset depreciates through time according to a definable schedule.
Valuation	
Trees are essential service providers and therefore should be considered assets.	Trees are amenities and therefore should be included in decision-making in other ways (not as assets).
Restoration and greening projects should be able to be funded as separate capital projects.	Restoration and greening projects can only be funded with capital funds if part of a grey infrastructure project.

have been largely left out of city-wide prioritization. GI continues to be managed in silos by multiple bureaus, some of which now have large maintenance deficits, especially of facilities that consist primarily of nature (i.e. tree plantings and restoration projects). While prioritization is done within each bureau separately, the differing magnitude of funding streams to each bureau makes it difficult to address all maintenance needs. For example, parks, wetlands, and street trees continue to be the responsibility of Parks & Rec without recognition of these facilities as infrastructure and, therefore, no reallocation of the budget even with the recognition of these facilities as GI within bureau. Also, GI facilities are often difficult to enter into AM software that doesn't recognize their key attributes.

GI development has been ongoing in Portland for roughly 25 years, making the city a GI pioneer. In 1991, when issued a Stipulation and Final Order (SFO) to address CSO violations, the EPA did not accept GI as a wet weather solution (they would not officially endorse GI until 2007 (EPA et al., 2007)). However, active citizens groups and progressive engineers advocated for GI throughout the 1990s, and eventually GI was integrated into Portland's CSO plan. Because of the success of the existing AM process in Portland to improve grey infrastructure maintenance, staff have advocated for compiling a standardized city-wide Green Asset Report to help the city systematically make investments in their GI network.

3.2. Methods

In this paper, I present one facet of my dissertation research. Throughout 23 interviews conducted with municipal staff at departments that manage GI in Portland, green AM emerged as an important theme. While other themes were also identified in these interviews (see Matsler (2017)), I present only discussion surrounding green assets in this paper.

Semi-structured interviews were first conducted with staff who self-identified as GI managers. Initial interviewees were contacts made through my work on GI projects and I used snowball sampling to contact additional staff engaged in AM generally (not necessarily GI-related work) to better understand the accounting KS at work in Portland.

All interview audio was transcribed by *Rev.com* and qualitatively coded using ATLAS.ti™. Initially, an a priori codebook was used to address the overarching research questions of my dissertation. Over 400 emergent codes were generated and then consolidated through the coding process (using Friese (2014)). A summary of each interview, including quotes, was shared with each interviewee prior to final analysis, allowing additional clarification.

Discourse analysis was used to illuminate KS dynamics. I define discourse following Hajer and Versteeg (2005) as

> an ensemble of ideas, concepts and categories through which meaning is given to social and physical phenomena, and which is produced and reproduced through an identifiable set of practices. (p. 175)

I understand the 'set of practices' here to be KSes (Miller and Munoz-Erickson, 2018). Therefore, through the use of discourse, I do not focus on interviewees as individuals but instead as representatives of an organization. This reveals KS dynamics by tracking the credibility of specific knowledge claims to different formal groupings of individuals (i.e. by discipline, organization, etc).

4. Results

Green AM is appealing to departments managing GI in Portland, including Portland's Bureau of Environmental Services (BES), the Parks and Recreation Bureau (Parks & Rec), and the Water Bureau. Staff are interested in using green AM to provide structure for increased funding and long-term investment in GI management:

> *Operations and maintenance dollars, those are a huge deal for us… Directing those appropriately is very important. And right now we're looking at, from a financial perspective, how do we really get some order and structure to that process?* (Parks & Rec staff)

However, efforts to operationalize an inventory, condition assessment, and prioritization process for green assets has encountered a number of KS challenges primarily around the valuation of urban nature. There are differing KSes at work in the various bureaus that manage GI in Portland (i.e. engineering and ecological KSes). And each of these KSes differs from the financial KS that prescribes AM procedures. This creates tension between differing definitions, metrics, and valuation techniques of nature throughout the city (summarized in Table 2).

Challenges to green AM stem primarily from the eco-techno hybridity of GI. The more biological, living components in a facility – facilities found towards the 'eco' end of the eco-techno spectrum (Fig. 1) – the less fit with current AM valuation processes. This was echoed in multiple interviews where GI was described as different from other assets:

> *The characteristics are not the same [for the green as for the grey assets], so you can't follow the same formula as you're…putting value on it. You just maybe need to put [GI] in a different bucket.* (BES staff)
> *[Asset valuation] is fairly straightforward to do for our sanitary and combined system…But assigning those values to the GI is something that is still in a state of flux for us.* (BES staff)

> *…Things are much more complex because there's all different characteristics of this new category of [green] assets.* (BES staff)

Here, I present the KS challenges around green AM as conflicts between "ecological" and "accounting" KSes. I use these terms as

shorthand to represent two different ways of understanding nature. While there are many ways of knowing nature (Dryzek, 1997), these were most prominent in the interviews I conducted. The "ecological" here represents a broad understanding of urban nature as ecosystems that provide services. This knowledge comes primarily from the academic field of ecology but also the practices of landscape architecture and forestry. In Portland, GI staff are mostly trained in these disciplines. The "accounting" shorthand here represents the municipal finance departments' view of nature as amenities. This KS is heavily influenced by engineering; in most bureaus, AM staff are senior engineers, able to inventory and track grey infrastructural assets (like pipes, pumping stations, etc.), while accountants at the city-wide level are experts on financial and accounting standards at large without specific focus in any one asset sector.

Attempts to integrate these KSes through the creation of a Green Asset Report encountered the challenges listed in Table 2. I highlight the most discussed of these challenges in the following su**b**-sections.

4.1. Measurement: GASB standards & depreciation

The most significant challenge observed in Portland between accounting and ecological KSes stems from the current incompatibility of the 'eco' components of GI with accounting standards. Financial accounting standards for municipalities are dictated by the Governmental Accounting Standards Board (GASB), as staff at the Office of Management & Finance (OMF) explained:

> *…what we have to do is very clearly defined by the Government Accounting Standards Board so we're not going to put things in here, [in the Comprehensive Annual Financial Report], that our financial auditors are going to come in and say 'you can't put that in'… There [are] very clear guidelines set up.* (OMF staff)

And current GASB standards offer no guidance regarding facilities that consist mostly or completely of biological components, meaning that they currently have "zero asset value":

> *What's the value of the trees in our parks?…Those are the kind of things that, from an accounting point of view, don't get reflected on the books… So, they have zero asset value.* (OMF staff)

Greenspaces are valued in other ways in city government (described in more detail in Section 4.2), but in AM processes their value is zero. Practitioners in bureaus that own green assets talked about the importance of changing these standards to improve GI maintenance and management:

> *Accounting rules are still different between gray and the green assets, so there's a concerted effort from a number of cities across the country to get the GASB accounting rules changed so that we can book GI more readily.* (BES staff)

> *We have to … determine a system where we can all value things that would make it countable to the accounting folks…* (BES staff)

But it is unclear if nature can be made to fit the usual characteristics of an asset. For example, assets are generally depreciated throughout their anticipated life cycle. They perform best just after they are built, then deteriorate through time in a fashion similar to the life cycle schedule pictured in Fig. 3. GI on the other hand often improves in functionality as vegetation matures, perhaps appreciating for decades:

> *Part of the nuance [is] that the US accounting system is based on the concept of depreciation and green assets are often appreciating. So, you can plant a sapling but ten years from now its value is higher than it was when you planted it, whereas when you build a building, you start depreciating it because in theory in 50 years its life cycle is…well, you don't have any value in that building anymore.* (Parks & Rec staff)

Fig. 4 displays the potential appreciation of trees, and shows how

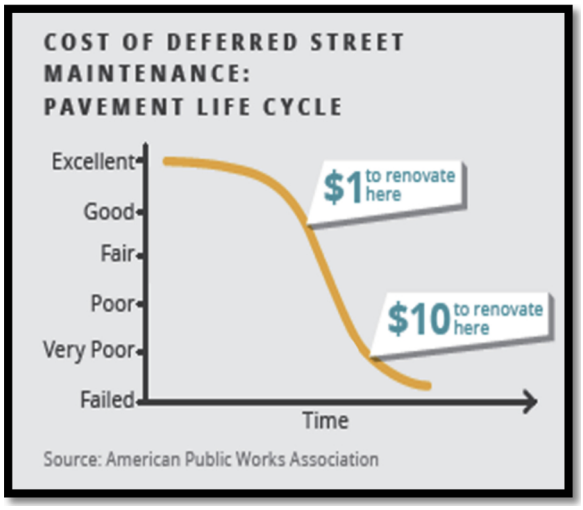

Fig. 3. Life cycle schedule of pavement from the 2017 Portland CAMG annual report draft.

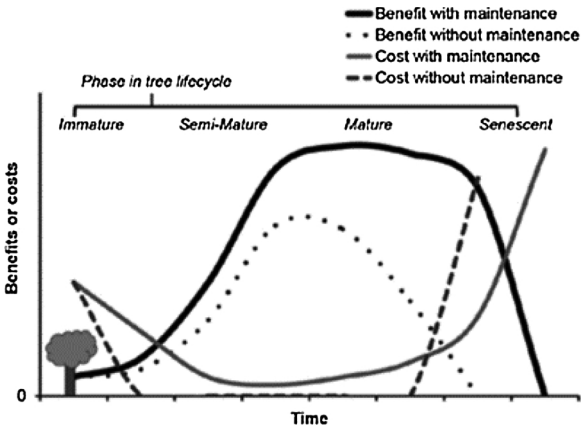

Fig. 4. Generalized benefits and costs of a street tree through its life cycle (from Vogt et al., 2015).

maintenance burden generally differs throughout the life cycle of a green versus a grey asset. These differences must be quantified and adapted into GASB standards for green assets to be "booked" appropriately on the accounting ledger. These differences are not easily reconcilable, as one asset manager expressed:

> *I don't know if [GI] is ever going to quite fit into what we've been doing year after year for the more traditional infrastructure.* (Water Bureau staff)

SASB was originally suggested by bureau-specific asset managers in Portland as an organization that could help the municipality address accounting standard issues. However, SASB does not provide any specific guidance on potential asset appreciation, and its private business focus means that SASB has not developed standards for municipal infrastructure specifically. Also, in discussions with staff that work on city-wide financial reporting, GASB was described as the only legitimate standards setting organization, which pointed out the marginal status of SASB:

> *I mean you could try to set up a set of accounting standards that looked at these other things. But auditors aren't going to audit them. It'll be just made up based on another set of standards… The underlying thing that people are going to look to is the GASB standards because that's what investors, bond holders, rating agencies and others will rely on.* (OMF staff)

4.2. Definition & Valuation: replacement cost vs service value

People embedded in the ecological KS have been working to better monetize ecosystem services (as described earlier) with the goal of better protecting the environment. But, while these values are useful in some arenas, ecosystem service valuations don't fit in accounting logic for AM even though they have dollar signs in front of them, as articulated by CAMG staff:

> *You're saving the amount of water that's going into your storm water runoff by having trees. So there's a value: we can measure it, we can put a dollar figure on it and GASB says, "That's just a paper exercise, it's not a value that we recognize as an actual asset that you can capitalize." So that's…where the value you're providing for the environment is not something GASB lets them book…* (Business Office staff)

The issue here is that AM uses replacement cost, not service value, to value assets because their goal is to assess all physical assets in a consistent way across all sectors that is comparable to all other businesses and municipalities. A replacement cost is simply how much it would cost to put in a new version of the facility that you currently have. While service value has a place – in setting levels of service for example (see Fig. 2) – it is not used for asset reporting purposes. This difference between service and replacement valuation approaches created tension when the green asset team met with the city-wide accounting team:

> *[The accountants] value that [pipe] based on what it costs to make it or replace it. But the green asset folks were thinking more along the lines of the value of the services that it provides. Teasing that out was interesting. I'm not sure we came to a resolution but clearly [the green asset folks] were thinking about…the value of the services that it provides as opposed to valuing it as pure replacement, which is how more commonly it's done for grey infrastructure. The Big Pipe, for example, it kept [pollution] from going into the river but BES doesn't include in their valuation of that project any external benefit to reducing pollution. [They only include pipe replacement value]…That was the difference in how people were coming to it which was interesting.* (Business Office staff)

Beyond the service vs replacement value tension, there are also definitional problems when attempting to find even the replacement value of GI because of its biological components:

> *'How do you value a tree' is always the question. It's a lot easier to talk about replacement value when you're talking about if this pipe fails, this is how much it would cost us to put in a new pipe. They have very good numbers for that kind of stuff and good metrics for the condition. They can talk about condition as based on what they know about their physical assets. It's a little harder to talk about with green assets.* (OMF staff)

This also intersects with the difficulties described above regarding asset appreciation:

> *What's the replacement value of the tree after it's grown five years? At a certain point, you can say how much it cost to plant a tree and how much it cost to buy a three inch caliper tree versus a two inch caliper tree…but when a tree gets to* 10 inches, you can't buy 10 inch *trees and successfully replant them. If you can, it's extremely expensive. …You can't replace an elm in the park across the street that's been growing for however many years. How do you think of that as a system and maintaining that system over time?* (OMF staff)

For many of these reasons, financial staff found it inappropriate to bring GI – and especially GI on the 'eco' side of the eco-techno spectrum – into AM. Instead, these facilities were described as useful in different arenas of government, particularly in setting policy agendas:

> *There are reasons to include [GI], there are reasons not to include [GI] and it just depends on what the desired outcome is. If the ultimate outcome is set policy for the city…that's one thing. But if you want to start to tie the value…into the prioritization of asset management decisions on a city level then you're talking about something totally different.* (Business Office staff)

In this way, accountants asserted that the lack of specific accounting standards did not mean that urban nature is not valued within the City of Portland. They explained that a number of important things in the city have quite small asset value. For example, some historic buildings were donated to the city, or bought for $1, which means they are recorded as having an asset value of $0 to $1. These historic buildings have undeniable value in a general sense. But they are not included as having a large asset value on the official accounting ledger. GI facilities were described as being similar:

> *The bottom line right now is that everything is at historical cost, unless you're really…going to be reselling this asset. We're not going to be reselling curbs and parks.* (Accounting Division)

Instead, urban nature is described as being a great promotional tool for politicians:

> *[Trees are] a way to bring people here. I want to go live there where they have lots of trees…[but] is it really an asset in that we could pay bills with it?* (Accounting Division)

In other words, as promotional amenities for economic development, GI facilities are still a part of the financial mix. But they are not considered appropriate to include as assets in official financial documents like the Comprehensive Annual Financial Report. This highlights the contrast between the accounting KS and the ecological KS: the credibility of the knowledge claim that nature is infrastructure is not only absent from the accounting KS, it is not appropriate or desirable.

Essentially, accounting and ecological KSes seem to be 'ships passing in the night' regarding the need for the development of green assets within AM. This mismatch displays an important insight from the KS literature:

> …even when new knowledge is created that can support novel solutions, this knowledge may not proceed to be used in the political process because there are other already established and powerful KSs informing the policy process... Moreover, assumptions about what knowledge is more credible in decision-making can ultimately affect how well we understand the dynamics of the system under study... (Munoz-Erickson, 2014, p.189)

4.3. Forward momentum?

Since City of Portland staff complied a draft Green Asset Report in 2016, new GASB guidance has emerged. GASB Statement No. 62 (GASB 62), while written in 2010, was promoted in 2018 as a solution to the lack of accounting standards for GI (Lohan, 2018; Earth Economics and WaterNow Alliance, 2018). GASB 62 focuses on "distributed infrastructure", which they define as:

> …technologies and practices that are decentralized and thus distributed across many locations… DI is often not under the direct control of utilities, because it resides on private property or property that is owned by other public entities. DI can include business or residential efficiency and water quality measures, reuse systems, consumer information technology, and various types of green infrastructure. (Earth Economics and WaterNow Alliance, 2018, p. 5, emphasis added)

Thus, many in the water utility sector, led by the San Francisco Public Utilities Commission among other municipalities, see this as an opportunity to begin to capitalize and bond GI incentive programs on private property, solving the problems around counting an extended

private network of facilities alongside centralized public facilities. This is indeed a problem that was mentioned in Portland:

> *Someone from BES was just saying the other day [that] for their sanitary sewer system, they own that. It's all theirs. The stormwater system, the combined sewer, overflow pipes and all of that…, that's under their control. But we're relying on not just our stuff but also the private sector for stormwater management and that makes it a little bit harder to quantify.* (OMF staff)

But while GASB 62 seems to be useful in helping solve this problem of raising bond funds for infrastructure with distributed ownership, it is silent on the value of urban nature, a key piece of the GI puzzle revealed here. Therefore, I predict that this new guidance will bolster implementation of GI facilities found on the 'techno' end of the eco-techno spectrum (e.g. bioswales) and facilities on the 'eco' end (i.e. forest patches, street trees, river restoration) will continue to be left off the accounting ledger.

Overall, the tensions described above show the hurdles that BES, Parks & Rec, and others face to make GI 'count' in city-wide AM. Green assets may never be incorporated directly into the official accounting processes of the city, but the collaborative effort of writing the draft Green Asset Report helped different silos in the city work together on GI. As Parks and Rec staff explain,

> *I think we have a long way to go. I think we're heading in the right direction, but we're just barely starting the trip.*

5. Discussion: standardization and depoliticization of nature

One of the important political shifts brought about by municipal implementation of GI is towards officially knowing nature as infrastructure, or as a legally-mandated-service provider, rather than a luxury. A primary challenge to this shift is the epistemological mismatch between ecological and accounting KSes as I have outlined above. I now consider the social and political consequences of this shift and the ways it increases the standardization of urban nature.

The standardization of nature through GI is an important force in nature's depoliticization. For example, when viewed as a luxury, urban nature is subject to political whims and philanthropic sentiments, much like it was during the progressive reform era (Rawson, 2004; Melosi, 2008; Eisenman, 2013). If standardized as infrastructure, urban nature would become more like any other technology, further black-boxed into the mundane technical details of the city and substantially buffered from changing political winds (Finewood et al., 2019) with legitimacy in the engineering and financial accounting KSes which dominate decision-making in the city.

How does the act of standardization accomplish the artifice of depoliticization? When nature becomes infrastructure, the political imperative of having nature in the city can move away from a moral or ethical appeal. This recategorization makes nature into something techno-mechanical, standardizing and routinizing it into the background. While Science and Technology Studies (STS) scholars argue that all technology is political (Winner, 1986), the appeal to 'nature as infrastructure' attempts to take nature out of the political spot-light and into the everyday black-boxes of technological sophistication. Then squishy, contingent values of nature can be left to other debates and urban nature becomes just another tool in the infrastructure toolbox, as commonplace as an electric pole or a stop-light. Following Pritchard (2011), it is the "depoliticization of technology" that makes it so appealing to make nature a technology.

This paper provides an example of this process: Portlanders hope to legitimate and make credible their use of nature as infrastructure by integrating it into standardized AM techniques. Because of the legal challenge BES faced in 2014, which asserted that GI was outside of the mission of the sewer utility, they know they must be more transparent about spending stormwater funds. But importantly, they must also show that they are spending money on legitimate and credible *infrastructure*.

The standardization of nature through GI depoliticization presents society with a double-edged sword: increased standardization means that urban nature can be further integrated into traditional AM processes, potentially providing much-needed re-prioritization of municipal budgets towards the maintenance of urban nature. At the same time, such standardization will further optimize GI to provide specific services over others, limiting its overall ecosystem service benefits and potentially silencing local voices and concerns (Finewood et al., 2019). As Carse (2012) found, making nature into infrastructure changed the relationship of farmers with their land in Panama, and allowed the government to assert more power over farmers' actions, erasing local knowledge and autonomy and creating a number of socio-political-environmental problems. Therefore, regardless of the status of GI facilites as green assets, decisions about GI implementation and responsibility must be open for wide discussion and negotiation within the planning process to avoid the pitfalls of state standardization processes of the past (Friedmann, 1993; Scott, 1998; Finewood et al., 2019).

6. Conclusion

While nature is increasingly being asked to perform as infrastructure, nature is still not integrated as an infrastructural asset on the local level. There are a variety of conceptual challenges that have stalled this integration including epistemological mismatches between financial accounting and ecological KSes that have been reviewed in this paper. These mismatches, if left unconfronted, have important consequences for the development and continued maintenance of GI in cities today. Some groups, like advocates of ecosystem services and SASB, work to translate knowledge claims about the value of nature between ecological and financial conceptual frameworks. While they remain fringe, the concept of nature as a service provider has gained traction at the municipal level in some places, as shown in the Portland's movement towards a city-wide Green Asset Report.

Current AM standards have consequences for the path of GI moving forward. For one, AM and GASB standards encourage the construction of facilities that consist primarily of human-built components, at the expense of more nature-based GI facilities like forest patches, riparian areas, and parks. More generally, the primary KS innovation highlighted in this paper is the transition of urban nature from being known as a luxury to being known as infrastructure. This is part of a larger trend globally to infrastructuralize nature (Carse, 2012) and to improve environmental conditions by drawing more robust links between healthy ecosystems and human health, happiness, and prosperity (Millennium Ecosystem Assessment, 2005). However, KS mismatches and challenges, like those identified in this paper, must be acknowledged and resolved if GI is to fulfill its (many) social and environmental promises.

Declaration of interest

None.

Funding

This material is based upon work supported by National Science Foundation IGERT Grant #0966376: "Sustaining Ecosystem Services to Support Rapidly Urbanizing Areas.

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