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Research article

A case-study based framework for assessing the multi-sector performance of green infrastructure

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ABSTRACT

Green infrastructure is emerging as a holistic stormwater management strategy that can also provide multi-sector benefits. Robust demonstration of project success can help leverage the appeal of green infrastructure to different sectors and open the door to a variety of funding opportunities. Yet comprehensively assessing the performance of these natural systems can be challenging, especially when communicating the benefits to a wide variety of stakeholders. A cohesive, well-described assessment structure may promote a higher degree of investor confidence by more comprehensively monitoring and measuring green infrastructure success. This paper develops a conceptual framework that incorporates a robust assessment component for communicating with potential investors through the inclusion of multiple evaluation methods, performance metrics, and risk categories. The applied performance of this framework is then validated using fourteen U.S. and international case studies. We found that our framework fit a wide range of projects while maintaining a degree of flexibility that did not sacrifice specificity when applied to individual case studies. This suggests that: 1) some GI projects already incorporate one or more evaluation methods; 2) a number of highly specific metrics—particularly social and economic performance metrics—exist that are capable of capturing a wide-range of benefits that can be easily integrated into a framework; 3) the incorporation of risk and risk management technique identification could be emphasized to increase investor confidence; 4) at least some degree of standardization across projects exists already which can help future project implementers design GI strategies that best fit their needs.

1. Introduction

1.1. Green infrastructure for holistic stormwater management

Urban stormwater infrastructure has traditionally been designed to capture and convey rainfall-induced runoff through a network of curbs, gutters, drains, and pipes, collectively known as grey infrastructure (Vineyard et al., 2015). Yet this approach to stormwater management can have significant shortcomings for effectively managing drainage as well as reducing pollutant loads that accumulate in runoff during transport (Burns et al., 2012). These conventional systems were often planned with a single-purpose (Center for Neighborhood Technology, 2010) and designed under the assumption of hydrologic stationarity, a notion that no longer holds true in the face of a changing climate (Milly et al., 2008). Additionally, new challenges are emerging as impervious surface area increases ubiquitously. Urban runoff volume is increasing with altered response peaks during storm events (Lee and Heaney, 2003; Mejía et al., 2014), which can result in frequent, and sometimes catastrophic, flooding and combined sewer overflow events (Montalto et al., 2007).

In many places, existing grey infrastructure is reaching the end of its design life and must be repaired or replaced while environmental regulations simultaneously demand more holistic solutions (Paola Bernal et al., 2012; The Center for Clean Air Policy, 2011; United States Forest Service, 2013). Beyond managing stormwater for pollution prevention and flood control, there is also increasing recognition that stormwater serves as a potentially valuable resource, especially in arid and semi-arid regions (Grant et al., 2013; Hering et al., 2013). There is an opportunity to move away from single-purpose stormwater infrastructure to emerging systems that address these challenges and opportunities while also providing broader benefits to society.

One solution gaining momentum globally is green infrastructure (GI). GI can be defined in many ways, but for this study is described as "a network of decentralized stormwater management practices … that

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can capture and infiltrate rain where it falls, thus reducing stormwater runoff and improving the health of surrounding waterways" (Fletcher et al., 2015) while preserving the quality and quantity of rain water for potential future use. Instead of conveying stormwater via impervious surfaces, GI attempts to mimic the natural environment through infrastructure like bioretention basins, green roofs, and permeable pavement. Decentralized GI is not meant to replace existing centralized infrastructure, but should instead be used to supplement current stormwater management networks. Integrating distributed GI into existing grey infrastructure systems can increase network resilience and flexibility by taking pressure off existing systems, delaying the need to build centralized infrastructure, and reducing energy used for conveyance.

GI solutions can offer many environmental, economic, and social benefits beyond improved stormwater management. These multi-sector benefits have been well documented (Demuzere et al., 2014; Lovell and Taylor, 2013); for example, a parklet not only provides stormwater management, but can also recharge groundwater, establish recreational space, and mitigate urban heat island effect. Situating and siting GI is thus not only a function of performance related to stormwater management, but for community improvement as well (Schifman et al., 2017; Simíc et al., 2017). Many scholars have also found that widespread implementation of GI will be critical for adapting to a changing climate (Foster et al., 2011; Gaffin et al., 2012; Grant et al., 2013; Kim and Kim, 2017).

GI implementation can be approached in a number of different ways. Although projects are thematically linked in their goal to more naturally manage stormwater, geographic and cultural context also shape how a GI project is implemented (Fletcher et al., 2015; Schifman et al., 2017). For instance, GI approaches in the U.S. may differ from those in other countries despite both having a shared goal to reduce stormwater volume. These differences could be related to a number of factors including stakeholder concerns, regulatory context, or differences in laws. Capturing these differences and similarities across scales, geography, and cultural context is thus critically important for pushing GI initiatives forward (Chocat et al., 2001; Fletcher et al., 2015; Zinger et al., 2013).

1.2. Financial evaluation and funding for GI projects

Despite the multi-sector benefits of GI, many barriers have prevented the widespread adoption of these systems worldwide. One major barrier is adequate funding (Dhakal and Chevalier, 2017); survey studies of stormwater practitioners show that securing funding is often the primary challenge in implementing a GI project (Keeley et al., 2013; Rowe et al., 2016). Robust and reliable funding sources and financing strategies are required to accelerate the integration of GI solutions into our current system (Quesnel et al., 2017). Recently, creative financing methods have been explored to facilitate the implementation of GI projects. These strategies include cost-sharing between public and private entities (Montalto et al., 2007), performance-based contracting (Appel et al., 2017; Goldman Sachs et al., 2016), stormwater fee programs (Keeley, 2011; Nickel et al., 2014; Niu et al., 2010), credit trading schemes (Thurston et al., 2003), and others. Many of these strategies bridge the funding gap by partnering with private actors to create a variety of public-private partnerships while also in some cases engaging customers more actively.

To better understand how GI projects successfully engage these kinds of strategies to unlock novel partnerships, previous researchers have looked across case studies to synthesize key takeaways. For example, Chini et al. (2017) examined GI plans across the U.S., finding that key components of successful plans include community involvement and communication, tailored evaluation methods and metrics, and iterative processes in development. Garrison and Hobbs (2011) found that utilities who have successfully created GI programs or projects have done so by involving private parties, creating dedicated funding sources, generating long-term GI plans, and increasing permitting efficiencies. Most related to this research is a study by Pakzad and Osmond (2016) that acknowledges the importance of measuring multi-sector GI functionality and consequently develops a set of performance indicators aimed at enhancing project outcome and funding opportunities.

While the importance of monitoring and evaluation has been found to be critical for widespread GI dissemination (Chini et al., 2017), it remains difficult for practitioners to assess exactly *how* to measure *which* performance metrics to decrease environmental, social, and economic risk and increase funding potential. This difficulty is particularly pronounced when considering the multi-sectorial nature of GI, where funders have varied interests and priorities. Without a more defined structure for evaluating, monitoring, and measuring GI, developers, utilities, and city planners are unable to demonstrate the multi-sector short-term and long-term benefits of GI systems to funders, regulators, and the public (Pakzad and Osmond, 2016).

1.3. Conceptual models and frameworks for assessing the multi-sector benefits of GI

Conceptual models, including frameworks, are one tool used to standardize GI project evaluation. Once developed, these frameworks can then be applied to specific projects to comprehensively address investor and stakeholder questions and concerns about GI project evaluation (Claver et al., 2007). One of the earliest models of the effects of GI on mental and physical health was presented by Freeman (1984). This model was then expanded upon by Pickett et al. (1997, 2001) who presented an integrated human ecosystem framework for biological, social, and physical components of urban systems with revisions by Grimm et al. (2000) that included impacts of land use. Tzoulas et al. (2007) and Austin (2014) then extended this work by introducing a conceptual model that integrated ecosystem services and function, social benefit and human health, and ecosystem health.

More recently, Pakzad and Osmond (2016) introduced a novel conceptual framework building on this past work (Freeman, 1984; Pickett et al., 1997, 2001; Tzoulas et al., 2007) by identifying and compiling selected criteria and key indicators of GI success. Their work hones in on the emerging need for more comprehensive and scalable GI performance indicators to identify, measure, and compare the multiple benefits of GI in achieving the level of urban sustainability required to meet shifting water demands and uncertain water supplies (Pakzad and Osmond, 2016). Despite the development of these many models aimed at GI performance measurement, a specific focus on funding and financing remains limited (Furlong et al., 2017).

1.4. Development and testing of applied conceptual models and frameworks to track project performance

To ensure that novel, conceptual models and frameworks are grounded in reality, it is important to validate these models using actual case studies (Shanks et al., 2003). Many efforts to examine the functionality of different models and evaluation methods focus on a single case study in a single location (Spatari et al., 2011; Vineyard et al., 2015; Wang et al, 2013). In the same vein, these studies all used the same evaluation method, LCA, to compare green and grey strategies (Spatari et al., 2011, Vineyard et al., 2015 and Wang et al., 2013). While this specificity is important, the need to examine both differences and similarities in GI at different scales and in different contexts is well documented (Chocat et al., 2001; Fletcher et al., 2015). We address this issue by validating our conceptual framework with a number of U.S. and international GI case studies to provide a more applied, holistic, and systematic method to monitor and measure GI successes through the lens of financing.

Our framework explicitly addresses the identified need for more rigorous, flexible, and data-driven assessment-based methods to

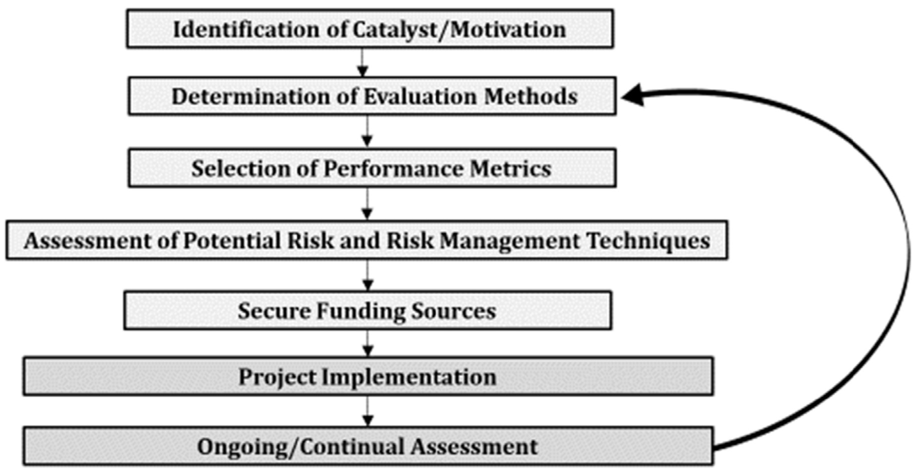

Fig. 1. Conceptual framework for project assessment of GI. The five lighter grey boxes are within the scope of this research.

evaluate GI performance more broadly. Specifically our framework and the subsequent validation using GI case studies is intended to addresses five critical questions:

1. What are the catalysts most commonly associated with the decision to undertake GI projects?
2. What evaluation method(s) do GI project implementers identify to assess performance over time?
3. What specific performance metrics do project implementers identify to measure the multiple benefits resulting from GI?
4. What types of risk are identified and how do various GI project plans attempt to mitigate those risks?
5. What funding sources are identified that support GI projects?

2. Methods and data

2.1. Framework development, data collection, and case-study based validation

Our conceptual framework is diagramed in Fig. 1 and, as previously noted, builds upon related frameworks in the risk adaptation decision-making space (Willows and Connell, 2003; Sayers et al., 2012; William and Stillwell, 2017). This framework can be used to: 1) employ more rigorous assessment methods to improve performance tracking over time, and; 2) enable access to greater funding opportunities.

After developing our framework, we conducted a global search to select fourteen GI projects located in the U.S. and internationally (Fig. 2, Table 1) that we could use to validate the conceptual framework and subsequently provide more specific and practical guidance around how current managers address each element in our conceptual framework. Here, we focus specifically on five parts of our framework: catalyst(s), evaluation methods, performance metrics, risk and risk management identification, and funding sources.

To select appropriate projects from around the globe, we applied a number of screens. First, we searched for locations using some combination of grey and green infrastructure to manage stormwater runoff. Second, we looked at projects implemented at the city-scale, as opposed to on one street or in one neighborhood. Lastly, we selected locations that represented a number of different biophysical, regulatory, and climatic contexts. For both the U.S. and international case studies, we selected cities from a variety of locations to capture variability in social attitudes as well as environmental contexts.

In our analysis, the distinction between U.S.- and internationally-based case allows us to assess the relationships between projects with similar and different regulatory contexts. For the case study analysis, we relied on publicly available information from planning documents, public materials, and peer-reviewed literature. Additionally, we did not track project outcomes owing largely to the fact that some of the selected projects are only beginning or are in the early stages of development. For projects that were completed or in later stages, we looked at earlier stage documentation as opposed to outcome reports to maintain consistency. In some cases, it was also difficult to find reported outcomes. Thus, our analysis mostly presents data on evaluations of metrics and risk mitigation strategies that are *planned*. Sources used to evaluate each project are presented in Table S1.

2.1.1. Project background

To provide insight into the similarities and differences between the fourteen case studies, we tracked project motivation, location, duration, and estimated cost as well as initial sources of capital and any barriers to initial project implementation. We used geographic location to track how well implementation strategies translated across cultural, physical, environmental, and governmental boundaries. Project timing was recorded to ensure that case studies were representative of a variety of stages in the lifespan of GI projects (e.g. some projects were nearly finished at the time of analysis while others were just beginning).

2.1.2. Project evaluation method

Case studies were analyzed to determine which, if any, formalized mechanisms were used to evaluate project performance and payback. Formalized methods to evaluate GI performance not only enhance the project's ability to meet with both fiscal and performance objectives, but also have the potential to enhance stakeholder and public engagement (Vandermeulen et al., 2011). We analyzed each of the fourteen case studies to determine: 1) the range of evaluation methods used to assess the success of a GI project; and, 2) the translatability of different evaluation methods across a range of social, environmental, cultural, and governmental contexts (e.g. which evaluation methods were most commonly deployed across case studies).

2.1.3. Performance metrics

Performance metrics and indicators provide multifaceted benefits to a number of different stakeholders (Pakzad and Osmond, 2016) and highlight project functionality at scale (Furlong et al., 2016). Additionally, performance metrics can be used to assess how successfully a project has met its objectives before, during, and after the implementation process. Each project in this study used a different set of performance indicators that fell into four broad categories:

1. **Environmental performance metrics** considered any indicators of project success that relate to environmental outcomes (e.g. decrease in water quality related pollution).

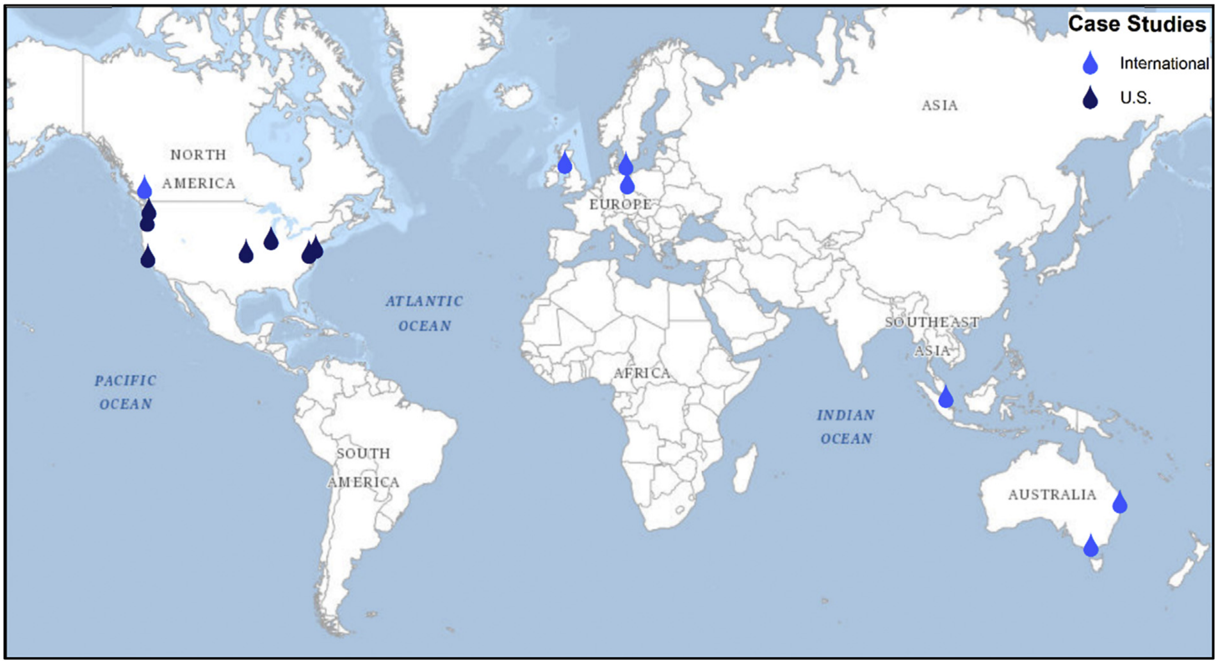

Fig. 2. Case study locations.

Table 1
A list of all case study locations, project names, and abbreviations used throughout this paper..

Case Study List		
Location	Project	Abbreviation
	International	
Melbourne, Australia	Little Stringybark Creek	MEL
Brisbane, Australia	WaterSmart City	BRI
Glasgow, Scotland	Glasgow Green Management	GLA
Malmo, Sweden	Urban Stormwater Management Program	MAL
Singapore, Singapore	Active Beautiful Clean (ABC) Water Programme	SIN
Vancouver, Canada	Integrated Rainwater Management Plan	VAN
Berlin, Germany	Biotope Area Factor (BAF) Initiative	BER
U.S.		
Philadelphia, PA	Green City, Clean Waters	PHI
Washington, D.C.	Stormwater Retention Credits Trading Program	WDC
Seattle, WA	RainWise Rebate Program	SEA
Portland, OR	Clean River Rewards Program	POR
Chicago, IL	Combined Sewerage Overflow Management Programs	CHI
Lenexa, KS	Rain to Recreation	LEN
San Francisco, CA	Managing Stormwater Using Green Infrastructure	SF

2. **Social performance metrics** considered any indicators of project success related to health, cultural, or social wellbeing (e.g. decrease in mortality correlated to the urban heat island effect).
3. **Technical performance metrics** considered any indicators of project success related to system performance (e.g. volume of stormwater captured, maintenance days, and operational cost reductions).
4. **Economic performance metrics** considered any indicators of project success related to direct or indirect financial returns from the project (e.g. percentage of project cost paid by auction or increase in residential property values).

There is some overlap between the different categories listed above. For instance, urban heat island, which we list as a social performance metric, can also be a technical performance metric (Virk et al., 2015; William et al., 2016). To simplify these overlaps, we used a combination of literature, project material, and best judgment to evaluate the primary aim of each metric and its measurement (e.g. urban heat island effect is often tracked as a reduction in mortality rate) and listed each identified metric in only one category. While this approach may not capture the full spectrum of the benefits each metric can provide, one of our primary interests was determining how projects track social and economic performance metrics, which are not commonly used in evaluation but have the potential to reach a more broad funding audience.

2.1.4. Risk and risk management

The ability to track identified risks and then link those risks to relevant risk mitigation strategies can dampen investment concerns from both public and private sectors (Furlong et al., 2017). To categorize and quantify risks identified within the case studies, we drew upon a report outlining GI risk perception by investors and developers put together by the Climate Policy Initiative (CPI) (Frisari et al., 2013). The report outlines four specific families of risk (Frisari et al., 2013), which included:

1. **Political, policy, and social risks**, which relate to governments, public opinion, individuals, or groups of individuals. These risks can be tied to legitimate exercise of political function (regulatory risk), reputation (social risk), resource appropriation (governance risk), or volatility and discrimination (political risks).
2. **Technical and physical risks**, which relate to technology or output and are linked to the physical attributes of an asset or its surrounding environment. This type of risk can be related to both construction or operational limitations and natural resource constraints.
3. **Market and commercial risks**, which are inherently tied to economic (e.g. market and commercial) factors and impact the economic value of inputs and outputs as well as financial resources for an asset.
4. **Outcome risks**, which are linked to the ability of public perception to impact support for a given project and thus its ability to meet with objectives and budget constraints.

We reviewed publicly-available literature and materials to determine what risks (e.g. lack of stakeholder buy-in or length of period to realize full project benefits) and risk management techniques (e.g. stakeholder meetings or using a data-driven approach) were identified for each project. We characterized risk management as any instrument, tool, or process designed or implemented to primarily address specific risks or types of risks (Frisari et al., 2013). We collected data on identified risks and risk management techniques independently of each other following the structure of most planning documents we read. We then clustered these risks using definitions and guidance provided by Frisari et al. (2013) according to the dominant risk category identified. For example, lack of stakeholder buy-in could relate to multiple categories but is primarily a social risk. We also used language clues in reviewed material such as "barrier" or "risk" whenever possible. Certain projects did a better job than others in breaking out risk types, which further assisted our delineation. Due to the variable nature of the data, we did not assign a value for the intensity of each risk identified; instead, we documented which risks were identified by each project and then identified the overlap between different case studies.

2.1.5. Project funding

We were interested in estimated or reported project costs and the accessibility of financial data regarding current, future, or past expenditures. Additionally, we focused on public and private funding sources identified across multiple case studies and whether these sources were used in combination with each other (e.g. public-private partnerships). Both costs and funding sources were tracked to provide a sense for how different projects overcame funding hurdles, if/how performance criteria and evaluation strategies were tied to the funding source, and to discover any differences between sources for capital costs and ongoing maintenance.

2.2. Project comparison

We used agglomerative hierarchical clustering, communicated through dendrograms, to investigate similarities across different case studies based on performance metrics and risk and risk management techniques. These two categories were then combined, in addition to the evaluation methods category, in a comprehensive dataset, which we also used to investigate relationships between projects. This analysis helped to identify similar projects and draw relevant comparisons that could eventually help these projects or projects like them optimize efficiency through relevant lessons learned. To create each dendrogram, we used Jaccard's distance:

$$d(r, v) = 1 - \mathrm{s(r, v)} = 1 - \frac{|r \cap v|}{|r \cup v|} \tag{1}$$

where (r, v) is the Jaccard distance and $s(r, v)$ is the Jaccard similarity computed by dividing the intersection of r and v (i.e. the number of elements in r AND in v) by the union of r and v (i.e. the total number of elements in r OR in v). The closer d (r, v) is to 0, the higher the similarity between components of r and s (e.g. more common data points). Conversely, the closer $d_j(r, v)$ is to 1, the higher the dissimilarity between components of r and s (e.g. fewer common data points). We then clustered elements using the complete-linkage clustering method, which incrementally combines each element cluster based on the smallest maximum distance between element pairs until all clusters are combined in to one. This was repeated for each of the three different datasets (performance metrics, risks and risk management, and the combination of both categories plus evaluation methods) detailed above.

3. Results

3.1. Project background

A variety of motivations were identified as project catalysts (Table 2). While stormwater runoff concerns, pollutant transport concerns, and combined sewage overflow were noted as motivations across international and U.S. projects, beautification and aesthetic concerns were limited to international case studies. Regulatory compliance, on the other hand, was noted in the context of several U.S. case studies and absent from discussion in the international context. Although GI projects spanned across a variety of timelines, the majority of the projects examined for this paper began after the year 2000. Several international case studies (e.g. Malmo and Berlin) began in the 1990's. Vancouver also provided some temporal diversity in that the initiative just began.

3.2. Project evaluation method

We found that only two formal broad evaluation methods were used in more than one case study in our analysis. Of these methods, triple bottom line (TBL) approach, was the most common: five of the seven U.S. case studies and two of the seven international case studies used the TBL approach. The TBL approach aims to capture the environmental, economic, and social benefits of a project or system, and the broad nature of the platform allows implementers to tailor the framework so that it best fits their needs. The second evaluation method mentioned by more than one city was Green Area Ratio (GAR). GAR was first introduced in Berlin but has since been adopted globally. The method assesses and rates distributed GI installations by assigning weighting factors depending on the type of GI (Keeley et al 2011; Emmanuel and Loconsole, 2015; Nickel et al., 2014).

While both TBL and GAR are promising approaches, the broad reliance on two methods indicates some degree of vulnerability. A study by Sridhar and Jones (2013) found that TBL is limited by an inability to represent interdependence between its three categories as well as a lack of objectivity and reliability in choosing what to measure. Research on GAR also found shortcomings and recommendations for future improvement, including an emphasis on monitoring and evaluation (Keeley, 2011).

With that said, several projects also formally or informally evaluated certain aspects of GI using site-specific tools instead of, or in addition to, more formalized evaluation method like TBL. Melbourne, for instance, used two different localized assessment tools. In conjunction with a trial uniform price auction financing strategy, the city also developed an Environmental Benefit Index calculator to compare customer bids for various projects (Fletcher et al., 2011). Additionally, the Before and After Control Reference Index (BACRI) method was used to measure the hydrologic performance of GI (e.g. success of channel restoration). This specific example emphasizes the importance of detailed assessment in enabling innovative financing strategies. Both of these site-specific tools focus on technical benefits. Considering the need to engage a diversity of funding sources for GI, there is significant opportunity for future site-specific evaluation tools to be developed in a more rapidly transferable way that includes a broader focus on social and economic benefits in particular.

3.3. Performance metrics

3.3.1. Environmental performance metrics

The most common environmental performance metric, mentioned by all except one case study, was measuring improvement in ecology and habitat, including increases in biodiversity, (Table 3, Fig. S1). Improvements to soil health and water quality and increases in air quality were also frequently mentioned, highlighting the carbon reduction and air quality benefits associated with GI. A minor degree of clustering was observed with respect to certain indicators. U.S. case studies, for instance, used volume of groundwater recharged and acres of impervious area treated more commonly than did their international counterparts. Likewise, improvements in soil health and decreases in per-capita water use were only discussed in international case studies.

Table 2
Project background information including motivation, duration, estimated cost, and funding sources. *Can be based on the time of first construction, the time when benefits were realized, or some other initial date depending on the project material.**For a variable number of elements.

Project	Motivation	Duration*	Estimated Cost**	Funding Sources
		International		
MEL	• Degradation from runoff	2008–2015		• Private Water Company • Research Funding
BRI	• Drought; waterway resiliency	2005-Present		• Local and National Government • Non-Profit Organization
GLA	• Enhance recreational and aesthetic value of parks and waterways	2011–2016		• Local Government • National Trusts • EU Funds
MAL	• Basement flooding and pollution risk reduction	1998–2002	$24 Million	• Private Housing Company • National Government • EU Funds • Local Government
SIN	• Enhance recreational and aesthetic value of parks and waterways	2006-Present		• National Government
VAN	• Reduction of pollutant transportation	2016-Present (Progress tracked from 2006)		• Local Government • Long term funding potential via: a) 'Polluter Pay' Model, b) fees and taxes
BER	• Enhance recreational and aesthetic value of parks and waterways • Historical emphasis on water security	1994-Present		• Property owners
		U.S.		
PHI	• Combined sewer overflow issues • Regulatory compliance	2009-Present (funded through 2034)	$1.2 Billion net value (2009)	• Local Water Department
WDC	• Stormwater runoff reduction	2016-Present	$12.75 Million	• Local Government
SEA	• Reduction of pollutant transportation • Combined sewer overflow issues	2013–2025	$1 Billion	• Local Government • Pooled Funding through Green Seattle Partnership (Non-Profit, Public Agencies, Local Businesses)
POR	• Water treatment cost reduction • Waterway resiliency	2006-Present		• National Government
CHI	• Combined sewer overflow issues	2004-Present (evolved from 2004 Sustainable Dev. Policy)	$50 million for 2014–2019*	• Public funding
LEN	• Reduction of pollutant transportation • Combined sewer overflow issues • Waterway resiliency • Regulatory compliance	2000–2020	Approx. $4.5 million yearly	• Local Cost-Share Program • Sales Tax • Stormwater Utility Fee • Development Fee
SFO	• Regulatory compliance • Reduction of pollutant transportation	2010 –Present (evolved from guidelines)	$239 Million for certain elements	• Local Government • Earthquake Safety and Emergency Response Bond

Close tracking of these more granular environmental benefits can enhance the opportunity to access private funding sources with a strong environmental and sustainability focus. None of the project materials reviewed as part of this analysis mentioned or tracked negative externalities related to green infrastructure development.

3.3.2. Social performance metrics

Social performance metrics are critical for enhancing multi-sector funding opportunities for GI. For example, robust identification and tracking of social performance metrics can be one way to attract funding from social impact bonds and community-based public-private partnerships (Sinha et al., 2017). In this study, reduction in urban heat island effect was the most widely tracked social metric across the case studies (Table 4, Fig. S2). This was particularly pronounced in the case of U.S. cities: all U.S. case studies except San Francisco mentioned reductions in heat-related mortality to demonstrate project success. Interestingly, more international cities planned to measure increases in civic participation and engagement in environmental issues to gage project performance. Increase in community willingness-to-pay was similarly used exclusively in international case studies. Brisbane also discussed increases in food production related to GI.

Several metrics were identified that generally related to improvements in quality of life, including those designed to measure improvements in personal economic security via higher property values, decreased turnover of tenants, and increased employment. Access to cooler and safer transportation options, access to clean water and air, decreased mosquito habitat, and improved access to recreation and green space were also noted. Improvements in safety risks related to catastrophic flooding, pollution, crime, and other hazards were also identified in our analysis.

Notably, several cities, including Berlin, Malmo, Philadelphia, and Chicago, also related GI projects to socio-environmental justice concerns to some degree or another. This relationship between socio-environmental justice and greened spaces is an increasingly compelling component of GI (William et al., 2017; Wolch et al., 2014). At the same time, Dooling (2009) found that there is also a potential for ‘eco-gentrification,’ as in the case of Seattle where efforts to restore riparian corridors disproportionately impacted the city's homeless population. In either context, the development and inclusion of quantifiable social performance metrics is greatly needed and could empower disadvantaged communities by tying project funding to the incorporation and demonstration of stakeholder goals in a measurable way.

3.3.3. Technical performance metrics

Data on technical performance metrics mentioned across case studies highlighted the importance of stormwater capture (Table 5, Fig. S3). The distribution of technical metrics across the U.S. and international case studies was similar and emphasized decreasing costs related to maintenance, water treatment, and operations resulting from a shift to decentralized GI. The distinction between ongoing maintenance costs and upfront capital costs with respect to infrastructure demands emerged as an important consideration. Because of this distinction, few cities tracked reduction in infrastructure needs (e.g. capital costs for plant installations, land or lot purchase, and material).

Table 3
Tabular results of environmental performance metrics findings. Shading represents the usage of the method, with darker rows showing methods that were used more frequently in the case studies evaluated.

1–13	INTERNATIONAL	MEL	BRI	GLA	MAL	SIN	VAN	BER	UNITED STATES	PHI	DC	SEA	POR	CHI	LEN	SF
Improvement in ecology; wildlife and aquatic habitat [variable]		•	•	•	•	•	•	•		•	•		•	•	•	•
Improvement in soil health and water quality [variable]		•	•		•	•	•	•		•	•		•	•		•
Increase in greened and/or recreational area [acres]			•	•						•		•	•	•	•	
Increase in air quality [AQI]				•				•		•	•	•		•		
Decrease in per capita water use [volume per person]		•	•				•									
Increase in groundwater recharge [volume]										•		•		•		
Decrease in mosquito habitat [acres]						•										

3.3.4. Economic performance metrics

Paralleling findings of both technical and environmental performance metrics, the most widely tracked economic metric across both international and U.S. projects was cost reductions related to changes in stormwater management (Table 6, Fig. S4). However, several international cities planned to track increases in residential and/or commercial property values, a metric that could be particularly useful when seeking multi-sector and/or private project funding. Interestingly, Philadelphia was the only U.S. city that explicitly noted increases in property value. Conversely, four of the seven U.S. case studies mentioned reduction in energy use related to the implementation of GI projects, while only one of the seven international case studies did the same. Little clustering was observed in measuring employment and other social benefits (including health benefits) with equal numbers of U.S. and international cities reportedly assessing project performance based on any reported increases. The remaining metrics were closely tied to the specific economic instruments used to fund GI projects (e.g. rebate per property, percentage of project cost paid by auction, increase in council tax revenue).

3.4. Risk and risk management

Identifying and communicating the perceived risks of different GI systems is essential for developers and municipalities to design and implement the most cost-effective and appropriate projects (William and Stillwell, 2017). The ability to track potential risks and to link those risks to relevant risk mitigation strategies can also dampen investment concerns from both public agencies and private industry (Furlong et al., 2017). Fig. 3A describes the distribution of specific risks identified by one or more case studies as they fit into each of the four families of risk (e.g. social, outcome, market, and technical risks) (Frisari et al., 2013). Fig. 3B describes the distribution of specific risk management techniques as they fit in to the same four categories. The number of identified risk and risk management techniques were evenly distributed among the four categories.

With that said, the categorical distribution of risks and risk management techniques does not illustrate the relative importance of each across different case studies—in most cases, the risks were all mentioned as equally important without implementers prioritizing different ones over others. We also found that there was a clear disconnect between these two seemingly related categories (Fig. 4). For example, more technical risks were identified than technical risk mitigation techniques planned and fewer social risks were identified than social risk mitigation techniques planned. In all four categories there was at least some degree of discrepancy between the number of risks identified and the number risk mitigation techniques identified.

U.S. projects identified the least number of market risks, whereas the international projects identified the least number of social risks. Yet both international and U.S. projects identified a number of social risk mitigation techniques (Fig. 4). One reason for the strong emphasis on social risk mitigation could be that many GI projects are still relatively unknown to the wider public, which operators are attempting to change through education and outreach before taking on more substantial risks. Moreover, our analysis of funding sources shows that several of the selected projects currently use or plan to use public funds and thus are incentivized to bolster their public profile and enhance public approval. Actual risks and risk management techniques employed may evolve over the project lifetime.

3.5. Project funding

Project costs and funding sources are presented in Table 2. Owing to the variety in size and scope of these projects, cost data provided by projects in literature and publicly available material was varied and the numbers provided are nominal. Some of these numbers are estimates while some reflect actual spending. Therefore it is very difficult to track funding, cost, and spending in a consistent and meaningful way across all case studies (e.g. capital costs only, maintenance only, combined

Table 4
Tabular results of the social performance metrics findings. Shading represents the usage of the metric, with darker rows indicating metrics used more frequently in the case studies evaluated.

	INTERNATIONAL							UNITED STATES						
	MEL	BRI	GLA	MAL	SIN	VAN	BER	PHI	DC	SEA	POR	CHI	LEN	SF
Reduction in urban heat island effect [decrease in related mortality rate]			•			•	•	•	•	•	•	•	•	
Increase in household participation and environmental awareness [number]	•		•	•	•	•					•	•		
Increase in value of property/city [% increase in residential property values, % decrease in tenant turnover]				•	•		•	•		•				•
Increase in recreation use [user days]		•			•		•	•			•			•
Increase in quality of life, including mental health benefits [% increase in urban neighborhood property values]					•		•	•				•	•	
Increase in educational value [$]					•		•	•				•	•	
Improvement to Health and Safety Risk Index (HSRI) and decrease in crime rate [HSRI; crime rate statistics]			•					•	•		•			
Increase in community willingness to pay [$]			•	•										
Reduction in unemployment rate [%]				•										•
Increase in street tree canopy [acres]		•								•				
Increase in transportation options [number]		•												•
Increase in access to cleaner air/water						•					•			
Increase in food production		•												
Decrease in odors														•

capital costs and ongoing maintenance combined). Based on available data, the low end estimate provided by Lenexa at $12.75 Million USD with a high end estimate of $1.2 Billion USD provided by Philadelphia. Specificity and transparency with respect to funding source was also variable.

A wide range of funding sources were identified to finance the GI projects including private water companies, research grants, both local and national governments, non-profit organizations, national trusts, European Union funding, private housing companies, property owners, local water departments, cost-share programs, taxes and fees, emergency response funding, and partnerships between public and private entities. Moreover, eight of the fourteen case studies identified a combination of funding sources (e.g. private companies and research or housing companies and national government). Notable among these combined funding efforts is the Green Seattle Partnership, which has successfully pooled resources from a number of different entities (e.g. social impact investors, a range of governmental agencies, local organizations, and environmental groups) and could be used as an exemplary case for future projects.

3.6. Project comparison

We used agglomerative hierarchical clustering to investigate similarity and dissimilarity across the case studies based on performance metrics (n = 56) and identified risk and risk management techniques (n = 38) (Fig. 5). Then, we combined these two categories and the evaluation method findings (n = 2) for all case study cities to examine relationships between composite assessment frameworks in all case studies (n = 96) (Fig. 6). In each of these figures, when Jaccard's distance (represented on the x-axis) is 0, projects are completely similar (e.g. share all common features). Conversely, when Jaccard's distance is 1 projects are completely dissimilar (e.g. share no common features).

Table 5
Tabular results of technical performance metrics findings. Shading represents the usage of the method, with darker rows showing methods that were used more frequently in the case studies evaluated.

	INTERNATIONAL							UNITED STATES						
	MEL	BRI	GLA	MAL	SIN	VAN	BER	PHI	DC	SEA	POR	CHI	LEN	SF
Increase in stormwater capture [volume]	•	•		•	•	•		•	•	•	•	•	•	•
Decrease in maintenance, treatment, and operational costs [$]		•		•	•	•			•		•		•	•
Decrease in infrastructure needs [cost, area, materials]		•				•		•	•					
Decrease in per capita water use [volume]	•	•				•								
Increase in treated area [acres]	•						•	•						
Decrease in emergency spills and pollution [number of incidents]												•	•	

Clustering based on performance metrics highlighted the versatility of the various social, economic, environmental, and technical metrics identified as part of this work. The largest cluster in Fig. 5A represents a diverse mix of international and U.S. cities, indicating that many of the identified metrics can be used to measure project success despite different regulatory and geographic contexts. For instance, the pairing of two Midwestern U.S. cities, Lenexa and Chicago, share the same level of similarity with the pairing of Berlin and Philadelphia. The fact that Seattle, Portland, and Vancouver all appear in different clusters similarly underscores that developed metrics were not necessarily bound to similar biophysical and climatological contexts.

The results of clustering based on risk and risk management (Fig. 5B) also underscored the universality of certain framework elements. Four of the five clusters (excluding Philadelphia) contain some mix of international and U.S. case studies, indicating that these projects identified similar risks and risk management strategies. And like performance metrics clusters, these risk clusters form independent of regulatory, geographical, social, and biophysical context. Notably, despite different regulatory oversight and geography, the pairing of Berlin and Chicago has the highest degree of similarity with respect risk and risk management.

Fig. 6 presents a composite dendrogram combining all collected data on risks and risk management, performance metrics, and evaluation methods. The results of this clustering analysis are exciting because

Table 6
Tabular results of economic performance metrics findings. Shading represents the usage of the method, with darker rows showing methods that were used more frequently in the case studies evaluated.

	INTERNATIONAL							UNITED STATES						
	MEL	BRI	GLA	MAL	SIN	VAN	BER	PHI	DC	SEA	POR	CHI	LEN	SF
Reduction in stormwater management costs [$]				•	•	•	•		•		•	•	•	•
Increase in residential and commercial property values [%]		•		•	•	•	•	•						
Decrease in energy use [MJ]							•	•		•	•	•		
Increase in employment, social benefits [number of full time jobs, $]			•	•				•						•
Average rebate per property [$]	•													
Percentage of project cost paid by auction [%]	•													
Increase in council tax revenue [$]			•											
Increase in recreational value of landscape [$]		•												

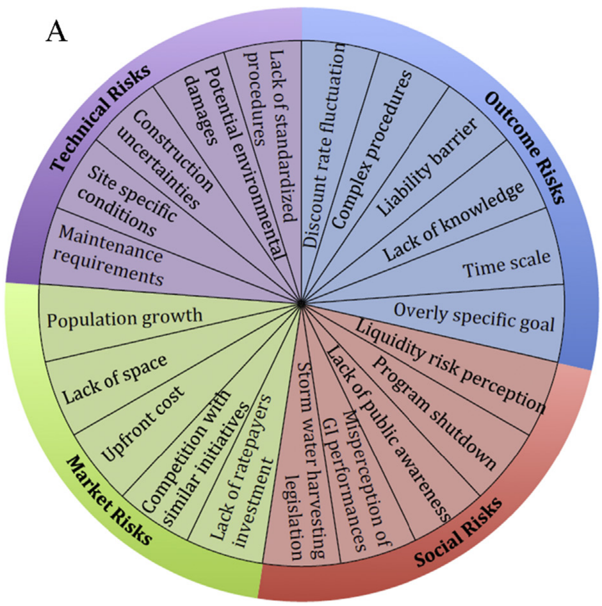

Fig. 3. Pie charts of (A) identified risks and (B) risk management strategies in the fourteen case studies.

they show that knowledge about how to evaluate, measure, and manage risk has the potential to be highly transferrable despite differences in regulation, geography, and climate. This clustering result challenges assumptions about the importance of geography, regulation, climate, and social attitudes in comprehensively assessing GI performance. For instance, San Francisco's assessment framework is more similar to Brisbane's than Brisbane's assessment framework is to Melbourne's, despite the Australian cities' shared regulatory and climatological context. Further pushing back against any siloing based on geography and climate, Vancouver exhibits a higher degree of similarity to Melbourne than it does to nearby Seattle, which experiences similar climate and precipitation.

Perhaps the most interesting finding of this clustering is that catalyst also appears to play a limited role in the clustering of different case studies. The highest degree of similarity exhibited between a pair of cities is between Berlin and Chicago, despite the fact that the projects were undertaken for different reasons, at different times, and by different groups of stakeholders. The key elements of Berlin's GI efforts were ostensibly motivated by a historical emphasis on water security owing to geographical isolation and private property owners' desire to enhance aesthetic value, while the key elements of Chicago's GI efforts were seemingly designed by public officials to deal with combined sewerage overflow issues. This in particular is a promising finding for multi-sectorial funders of GI who may not have the time or desire to develop a comprehensive assessment framework for each different objective.

3.7. Conceptual framework results

We incorporated the results of our case study analysis into our original conceptual framework (Fig. 2) to create a more detailed outline of how our framework operates in an applied context (Fig. 7). We conducted this post-hoc analysis for two reasons. First, by feeding each case study through the framework and incorporating the results of our analysis, we confirmed the framework's ability to represent the actual workflow of financing and implementing GI programs and projects. Second, the selected case studies vary widely in geography, climate, regulatory context, intent and motivation, and time period. In drawing upon this variability, we were able to better examine the overall adaptability and flexibility performance of our framework. Our intention in developing this framework is that a project implementer could use it as a tool to more robustly demonstrate project measurability to potential or current funders. Our framework organizes this process as follows:

1. A specific type of GI project is selected based on the needs and

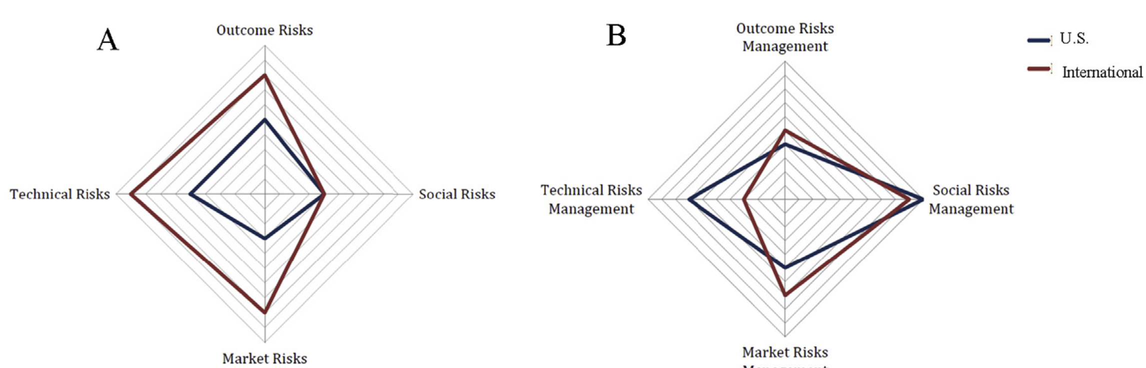

Fig. 4. Spider graph illustrating the relationship between (A) identified risks and (B) risk management strategies distributed across international and U.S. case studies. Each point on the spoke represents the total number of risks identified for all seven case studies. For example, Portland and Chicago both identified ratepayer unwillingness to invest as a market risk and San Francisco identified rate payer competition as a market risk. Therefore, in Fig. 4A there were a total of three market risks identified by U.S. case studies.

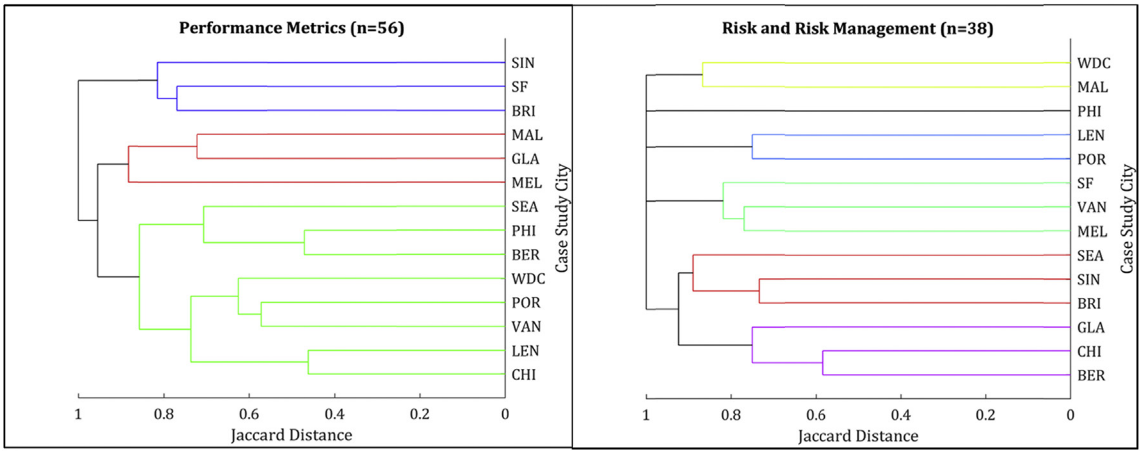

Fig. 5. A) Performance Metrics Dendrogram; B) Risk and Risk Management Dendrogram. Each color represents a distinct cluster that formed based on Jaccard's distance. In each of these figures, when Jaccard's distance (represented on the x-axis) is 0, projects are completely similar (e.g. share all common features). Conversely, when Jaccard's distance is 1 projects are completely dissimilar (e.g. share no common features). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

values of the project;

2. An evaluation method or combination of methods is identified;
3. Performance metrics are selected that range across the four different categories (environmental, social, technical, economic) to match project goals;
4. Risks and risk management techniques are identified. Categorizing risks as either social, technical, market, or outcome based can assist in addressing a broader array of investor concerns;
5. A diverse funding portfolio is established once assessment components have been addressed;
6. The GI project is implemented and the assessment elements are continually revisited to ensure optimal project performance measurability and monitoring.

4. Discussion

Evaluating our conceptual framework through the lens of several diverse case studies revealed key findings about the development of GI evaluation methods, performance metrics, and risk assessment and management methods. By promoting greater reliability in measuring and monitoring GI project performance, our framework can assist stakeholders in navigating barriers in attracting public, private, and multi-sector sector funding opportunities for decentralized GI projects.

Cities cited a number of reasons that led them to undertake GI projects beyond improved stormwater management; U.S. case studies most frequently cited regulatory compliance whereas international case studies were also interested in a project's aesthetic benefits. We also examined which (if any) evaluation methods were selected by each project, finding that a limited number of common, flexible, and broad evaluation methods were used to facilitate more rigorous analysis of GI benefits. The TBL method in particular was the most popular across different geographic, political, social, and environmental boundaries. While certain site-specific evaluation methods were used by some cities, these tools were primarily focused on technical benefits. Modifying these site-specific tools to include a broad suite of multi-sector metrics could engage a more diverse set of funders.

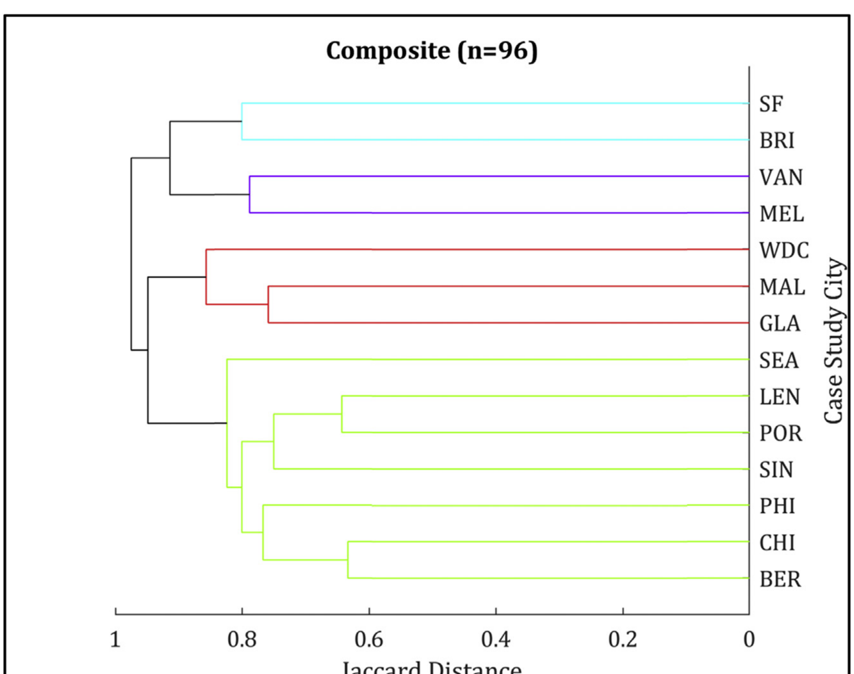

Fig. 6. Dendrogram assessing clustering among across all case study cities based on performance metrics, identified risk and risk management techniques, and evaluation methods. Each color represents a distinct cluster that formed based on Jaccard's distance. In each of these figures, when Jaccard's distance (represented on the x-axis) is 0, projects are completely similar (e.g. share all common features). Conversely, when Jaccard's distance is 1 projects are completely dissimilar (e.g. share no common features). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

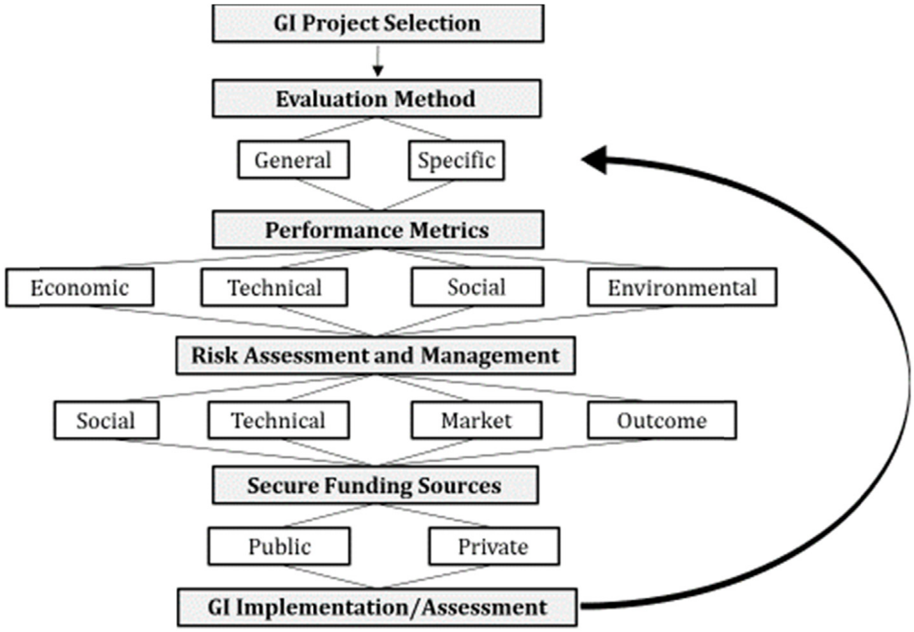

Fig. 7. Conceptual framework for project assessment of GI refined with the inclusion of results from the fourteen case studies.

International and U.S. case studies identified robust, well-developed performance metrics describing an impressive range of environmental, social, technical, and economic outcomes. All, but one case study, prioritized improvements to habitat and ecology as key indicators of environmental success. Our findings also supported the linkages between GI and improvements in soil health as well as water and air quality. We found that projects identified a suite of well-developed social metrics despite little mention of social motivation as a reason for undertaking projects. Many social metrics also included a rigorous quantitative component; for instance, some projects tracked the decreased number of deaths associated with the urban heat island effect. These social metrics could be particularly useful for impact investors interested in quantifying the social benefit of GI projects. The technical metric of improving stormwater management was unsurprisingly the common goal for many projects. Many U.S. case studies related economic performance to reduced stormwater management costs and decreased energy use. Interestingly, far more international cities tracked increased residential and commercial property values and employment. Additionally, there were a number of economic performance metrics specifically tailored to enable different financing mechanisms (e.g. reverse auction, average rebate per property). The combination of robust social and economic metrics, in addition to more described environmental metrics, highlights the multi-sector nature of GI projects. Measuring these benefits can attract investors with diverse social, environmental, and sustainability interests.

International case study implementers perceived more risks—particularly technical, outcome, and market-based risks—in total than did their U.S. counterparts. The relationship between identified risks and risk management methods was one of the most interesting dynamics revealed through our analysis. While both U.S. and international case studies recognized fewer social risks in comparison with technical, outcome, and market risks, all but one case study outlined robust social risk mitigation strategies. Social risk mitigation may be a focal area of concern and one where the consequences of an unmanaged risk are the greatest. Alternatively, we collected all of our data from publicly available sources and the emphasis in these materials could be more heavily weighted towards social risk mitigation. In either case, this highlights that robust social risk mitigation strategies were frequently assigned a relatively higher level of priority despite the identification of relatively fewer social risks.

Specific information on funding was limited and cost estimates varied from actual cost to estimates of future cost. Moreover, some projects only revealed partial project costs while others included estimates of an entire program's net worth. The size of the city also impacts the potential budget in such a way that drawing meaningful comparisons is inherently more difficult. Moreover, the distinction between capital costs and ongoing operations and maintenance costs was not always clear. These data gaps point to a need for the inclusion of more accurate tracking of funding and/or financial transparency in public materials. Future efforts using surveys to gather information about GI planning could provide insights into funding realities.

Several case studies in the U.S. and internationally cited some form of government funding as a source for GI projects. Interestingly, only one case study city relied exclusively on private funding. Most projects cited both public and private funding sources (e.g. Malmo) including some that used unique combinations of partners (e.g. Green Seattle Partnership). The Green Seattle Partnership is a particularly appealing case study of cross-sectorial collaborative funding in that the program successfully pools resources from public agencies, non-profit organizations, local businesses, and local government, all of which are likely to have variable funding aims.

Overall our clustering analysis showed that catalyst, location, biophysical, regulatory, social, and environmental context play a limited role in shaping a GI assessment framework. For GI implementers, this finding is exciting because it indicates that there may be certain standardized elements that can measure project successes across a variety of different scales, regions, and contexts. Additionally, it represents an important opportunity for opening up new channels to communicate lessons learned beyond geographic neighbors and/or cities with similar regulation. The apparent universality of certain elements indicates that key, well-developed elements can satisfy a broad range of project goals related to regional realities, stakeholder inputs, and/or funding intents.

To encourage GI implementation at the scale necessary to address 21st century challenges, new partnerships are needed. As project implementers look to enhance and unlock new sources of funding, the ability to better communicate, demonstrate, and measure the multi-sectorial benefits of GI to wider variety of potential funders is critical. Our work demonstrates that many of the elements needed to successfully develop a compelling assessment framework are already in place throughout the globe. Several general and site-specific evaluation methods can be built upon and improved to enhance project measurability over time; some of these methods also already link evaluation to funding in a way that could be expanded upon to accommodate more diverse funding sources. A robust suite of environmental, social, economic, and technical performance metrics aimed at capturing the multi-sector benefits of GI also already exists. Notably, quantifiable and trackable social and economic performance metrics were identified in projects throughout the North America, Europe, Asia, and Australia. A large number of projects have also found meaningful ways to identify both risk and risk management techniques, indicating that there are a number of options for discussing and addressing risks with potential funders. By combining key elements of project implementation, our framework provides an outline for projects seeking to enhance measurability and communicability to funders in a flexible and applied way.

5. Conclusion

Green infrastructure is a promising solution to the larger problems of aging water infrastructure, urbanization, and increasing water demand across a number of sectors. Implementing GI on the scale necessary to meet these various environmental and regulatory requirements, however, necessitates overcoming a number of barriers including access to funding and design of suitable financing strategies. Without a rigorous and scalable model that facilitates better performance assessment of GI projects, attracting investment remains difficult. One particular avenue for enhancing the assessment of GI performance is the development of comprehensive conceptual frameworks and models that can help implementers know how to systematically monitor and measure GI performance over time. Yet these models also need to be developed in such a way that they can be related back to an applied context.

This paper puts forward a conceptual model that integrates three key components of assessment to increase funding opportunities: evaluation method(s), performance metrics, and risk identification and risk management techniques. Our results can be used both in future research to gain deeper insight into what makes a GI financially feasible as well as by practitioners looking to implement programs or projects themselves. One particular avenue that is ripe for further research is tracking particular project outcomes as they relate back to the evaluation methods, performance metrics, and risk analysis used. This would allow both managers and investors to gain a better sense for what combination of assessment tools is best suited to specific contexts and how those assessment tools may be refined to promote greater project performance.

Our research also points to the broader need to incorporate the various benefits humans accrue from functional ecosystems—or ecosystem services—in to the decision-making space. This research only touched on the potential for the appraisal of and payment for ecosystem services in more natural stormwater management. By assigning some financial value to the suite of benefits identified through our analysis, it may be possible to make an ever more substantial case for the importance of GI moving forward.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jenvman.2018.06.029.

References

Appel, T., Bezak, B., Lisle, J., 2017. DC water green infrastructure financing: pay for success can help water utilities pursue innovative solutions. J. Am. Water Work. Assoc. 109, 26–31. http://dx.doi.org/10.5942/jawwa.2017.109.0131.

Austin, G., 2014. Green Infrastructure for Landscape Planning: Integrating Human and Natural Systems. Routledge.

Burns, M.J., Fletcher, T.D., Walsh, C.J., Ladson, A.R., Hatt, B.E., 2012. Hydrologic shortcomings of conventional urban stormwater management and opportunities for reform. Landsc. Urban Plann. 105, 230–240. http://dx.doi.org/10.1016/j.landurbplan.2011.12.012.

Center for Neighborhood Technology, 2010. The value of green infrastructure: a guide to recognizing its economic, environmental and social benefits. Proc. Water Environ. Fed. 1–76. http://dx.doi.org/10.2175/193864711802639741.

Chini, C.M., Canning, J.F., Schreiber, K.L., Peschel, J.M., Stillwell, A.S., 2017. The green experiment: cities, green stormwater infrastructure, and sustainability. Sustainability 9, 105. http://dx.doi.org/10.3390/su9010105.

Chocat, B., Krebs, P., Marsalek, J., Rauch, W., Schilling, W., 2001. Urban drainage redefined: from stormwater removal to integrated management. Water Sci. Technol. 43, 61–68.

Claver, E., López, M.D., Molina, J.F., Tarí, J.J., 2007. Environmental management and firm performance: a case study. J. Environ. Manag. 84, 606–619. http://dx.doi.org/10.1016/j.jenvman.2006.09.012.

Demuzere, M., Orru, K., Heidrich, O., Olazabal, E., Geneletti, D., Orru, H., Bhave, A.G., Mittal, N., Feliu, E., Faehnle, M., 2014. Mitigating and adapting to climate change: multi-functional and multi-scale assessment of green urban infrastructure. J. Environ. Manag. 146, 107–115. http://dx.doi.org/10.1016/j.jenvman.2014.07.025.

Dhakal, K.P., Chevalier, L.R., 2017. Managing urban stormwater for urban sustainability: barriers and policy solutions for green infrastructure application. J. Environ. Manag. 203, 171–181. http://dx.doi.org/10.1016/j.jenvman.2017.07.065.

Dooling, S., 2009. Ecological gentrification: a research agenda exploring justice in the city. Int. J. Urban Reg. Res. 33, 621–639.

Emmanuel, R., Loconsole, A., 2015. Green infrastructure as an adaptation approach to tackling urban overheating in the Glasgow Clyde Valley Region, UK, Landsc. Urban Plan. 138, 71–86. http://dx.doi.org/10.1016/j.landurbplan.2015.02.012.

Fletcher, T.D., Walsh, C.J., Bos, D., Nemes, V., RossRakesh, S., Prosser, T., Hatt, B., Birch, R., 2011. Restoration of stormwater retention capacity at the allotment-scale through a novel economic instrument. Water Sci. Technol. 64 (2), 494–502. http://dx.doi.org/10.2166/wst.2011.184.

Fletcher, T.D., Shuster, W., Hunt, W.F., Ashley, R., Butler, D., Arthur, S., Trowsdale, S., Barraud, S., Semadeni-Davies, A., Bertrand-Krajewski, J.-L., Mikkelsen, P.S., Rivard, G., Uhl, M., Dagenais, D., Viklander, M., 2015. SUDS, LID, BMPs, WSUD and more – the evolution and application of terminology surrounding urban drainage. Urban Water J. 12, 525–542. http://dx.doi.org/10.1080/1573062X.2014.916314.

Foster, J., Lowe, A., Winkelman, S., The Center for Clean Air Policy, 2011. The Value of Green Infrastructure for Urban Climate Adaptation (Washington, DC). .

Freeman, H. (Ed.), 1984. Mental Health and the Environment. Churchill Livingston, London.

Frisari, G., Hervé-mignucci, M., Micale, V., Mazza, F., 2013. Risk gaps: a map of risk mitigation instruments for clean investments. Clim. Policy Initiat. Br. 5–6.

Furlong, C., De Silva, S., Gan, K., Guthrie, L., Considine, R., 2017. Risk management, financial evaluation and funding for wastewater and stormwater reuse projects. J. Environ. Manag. 191, 83–95. http://dx.doi.org/10.1016/j.jenvman.2017.01.007.

Furlong, C., De Silva, S., Guthrie, L., 2016. Planning scales and approval processes for IUWM projects; lessons from Melbourne, Australia. Water Pol. 18, 783–802. http://dx.doi.org/10.2166/wp.2015.118.

Gaffin, S.R., Rosenzweig, C., Kong, A.Y.Y., 2012. Adapting to climate change through urban green infrastructure. Nat. Clim. Change 2http://dx.doi.org/10.1038/nclimate1685. 704–704.

Garrison, Noah, Hobbs, Karen, 2011. Rooftops to Rivers II: Green Strategies for Controlling Stormwater and Combined Sewer Overflows. Natural Resources Defense Council.

Goldman Sachs, DC Water and Sewer Authority, Calvert Foundation, 2016. FACT SHEET: DC Water Environmental Impact Bond.

Grant, S.B., Fletcher, T.D., Feldman, D., Saphores, J.D., Cook, P.L.M., Stewardson, M., Low, K., Burry, K., Hamilton, A.J., 2013. Adapting urban water systems to a changing climate: lessons from the millennium drought in southeast Australia. Environ. Sci. Technol. 47, 10727–10734. http://dx.doi.org/10.1021/es400618z.

Grimm, N.B., Grove, J.G., Pickett, S.T.A., Redman, C.L., 2000. Integrated Approaches to Long-Term Studies of Urban Ecological systems urban ecological systems present multiple challenges to ecologists—pervasive human impact and extreme heterogeneity of cities, and the need to integrate social and ecological approaches. Bioscience 50, 571–584. http://dx.doi.org/10.1641/0006-3568(2000)050[0571:iatlto]2.0.co;2.

Hering, J.G., Waite, T.D., Luthy, R.G., Drewes, J.E., Sedlak, D.L., 2013. A changing framework for urban water systems. Environ. Sci. Technol. 47, 10721–10726. http://dx.doi.org/10.1021/es4007096.

Keeley, M., 2011. The Green Area Ratio: an urban site sustainability metric. J. Environ. Plann. Manag. 54, 937–958. http://dx.doi.org/10.1080/09640568.2010.547681.

Keeley, M., Koburger, A., Dolowitz, D.P., Medearis, D., Nickel, D., Shuster, W., 2013. Perspectives on the use of green infrastructure for stormwater management in cleveland and milwaukee. Environ. Manag. 51, 1093–1108. http://dx.doi.org/10.1007/s00267-013-0032-x.
Kim, S., Kim, B., 2017. The effect of urban green infrastructure on disaster mitigation in Korea. Sustainability 9, 1026. http://dx.doi.org/10.3390/su9061026.
Lee, J.G., Heaney, J.P., 2003. Estimation of urban imperviousness and its impacts on storm water systems. J. Water Resour. Plann. Manag. 129, 419–426. http://dx.doi.org/10.1061/(ASCE)0733-9496(2003)129:5(419).
Lovell, S.T., Taylor, J.R., 2013. Supplying urban ecosystem services through multifunctional green infrastructure in the United States. Landsc. Ecol. 28, 1447–1463. http://dx.doi.org/10.1007/s10980-013-9912-y.
Mejía, A., Daly, E., Rossel, F., Jovanovic, T., Gironás, J., 2014. A stochastic model of streamflow for urbanized basins. Water Resour. Res. 50, 1984–2001. http://dx.doi.org/10.1002/2013WR014834.
Milly, P.C., Betancourt, J., Falkenmark, M., Hirsch, R.M., Kundzewicz, Z.W., Lettenmaier, D.P., Stouffer, R.J., 2008. Climate change. Stationarity is dead: whither water management? Science (80-.) 319, 573–574. http://dx.doi.org/10.1126/science.1151915.
Montalto, F., Behr, C., Alfredo, K., Wolf, M., Arye, M., Walsh, M., 2007. Rapid assessment of the cost-effectiveness of low impact development for CSO control. Landsc. Urban Plann. 82, 117–131. http://dx.doi.org/10.1016/j.landurbplan.2007.02.004.
Nickel, D., Schoenfelder, W., Medearis, D., Dolowitz, D.P., Keeley, M., Shuster, W., 2014. German experience in managing stormwater with green infrastructure. J. Environ. Plann. Manag. 57, 403–423. http://dx.doi.org/10.1080/09640568.2012.748652.
Niu, H., Clark, C., Zhou, J., Adriaens, P., 2010. Scaling of economic benefits from green roof implementation in Washington, DC. Environ. Sci. Technol. 44, 4302–4308. http://dx.doi.org/10.1021/es902456x.
Pakzad, P., Osmond, P., 2016. Developing a sustainability indicator set for measuring green infrastructure performance. Procedia Soc. Behav. Sci. 216, 68–79. http://dx.doi.org/10.1016/j.sbspro.2015.12.009.
Paola Bernal, D., Restrepo, I., Paola BERNAL, D., Restrepo, I., 2012. Key Issues for Decentralization in Municipal Wastewater Treatment Key Issues for Decentralization in Municipal Wastewater Treatment Key Issues for Decentralization in Municipal Wastewater Treatment.
Pickett, S.T.A., Burch, W.R., Dalton, S.E., Foresman, T.W., Grove, J.M., Rowntree, R., 1997. A conceptual framework for the study of human ecosystems in urban areas. Urban Ecosyst. 1, 185–199.
Pickett, S.T.A.T.A., Cadenasso, M.L.L., Grove, J.M.M., Nilon, C.H.H., Pouyat, R.V.V., Zipperer, W.C.C., Costanza, R., 2001. Urban ecological systems: linking terrestrial ecological, physical, and socioeconomic components of metropolitan areas. Annu. Rev. Ecol. Systemat. 32, 127–157. http://dx.doi.org/10.1146/annurev.ecolsys.32.081501.114012.
Quesnel, K.J., Ajami, N.K., Wyss, N., 2017. Accelerating the integration of distributed water solutions: a conceptual financing model from the electricity sector. Environ. Manag. 60, 867–881. http://dx.doi.org/10.1007/s00267-017-0914-4.
Rowe, A.A., Rector, P., Bakacs, M., 2016. Survey results of green infrastructure implementation in New Jersey. J. Sustain. Water Built Environ. 2, 1–6. http://dx.doi.org/10.1061/JSWBAY.0000810.
Sayers, P., Galloway, G., Hall, J., 2012. Robust decision-making under uncertainty. In: Sayers, P. (Ed.), Flood Risk: Planning, Design and Management of Flood Defense Infrastructure. ICE Publishing, London, pp. 281–303.
Schifman, L.A., Herrmann, D.L., Shuster, W.D., Ossola, A., Garmestani, A., Hopton, M.E., 2017. Situating green infrastructure in context: a framework for adaptive socio-hydrology in cities. Water Resour. Res. 53, 10139–10154. http://dx.doi.org/10.1002/2017WR020926.
Shanks, G., Tansley, E., Weber, R., 2003. Using ontology to validate conceptual models. Commun. ACM 46, 85. http://dx.doi.org/10.1145/944217.944244.
Simíc, I., Stupar, A., Djokíc, V., 2017. Building the green infrastructure of Belgrade: the importance of community greening. Sustainability 9. http://dx.doi.org/10.3390/su9071183.
Sinha, S.K., Pettit, R., Ridgway, J., Eidson, A., Silfen, J., Peralta, G., Cannito, G., 2017. Assessing the Market Size for Large-scale Adoption of Green Infrastructure in the Great Lakes Basin. Environmental Consulting & Technology, Inc.
Spatari, S., Yu, Z., Montalto, F.A., 2011. Life cycle implications of urban green infrastructure. Environ. Pollut. 159, 2174–2179. http://dx.doi.org/10.1016/j.envpol.2011.01.015.
Sridhar, K., Jones, G., 2013. The three fundamental criticisms of the Triple Bottom Line approach: an empirical study to link sustainability reports in companies based in the Asia-Pacific region and TBL shortcomings. Asian J. Bus. Ethics 2 (1), 91–111.
The Center for Clean Air Policy, 2011. THE VALUE of GREEN INFRASTRUCTURE for URBAN CLIMATE ADAPTATION.
Thurston, H.W., Goddard, H.C., Szlag, D., Lemberg, B., 2003. Controlling storm-water runoff with tradable allowances for impervious surfaces. J. Water Resour. Plann. Manag. 129, 409–418. http://dx.doi.org/10.1061/(ASCE)0733-9496(2003)129:5(409).
Tzoulas, K., Korpela, K., Venn, S., Yli-Pelkonen, V., Kaźmierczak, A., Niemela, J., James, P., 2007. Promoting ecosystem and human health in urban areas using Green Infrastructure: a literature review. Landsc. Urban Plann. 81, 167–178. http://dx.doi.org/10.1016/j.landurbplan.2007.02.001.
United States Forest Service, 2013. Greening the Grey Green Infrastructure for Sustainable Development Funder Sponsors Global Sustainability.
Vandermeulen, V., Verspecht, A., Vermeire, B., Van Huylenbroeck, G., Gellynck, X., 2011. The use of economic valuation to create public support for green infrastructure investments in urban areas. Landsc. Urban Plann. 103, 198–206. http://dx.doi.org/10.1016/j.landurbplan.2011.07.010.
Vineyard, D., Ingwersen, W.W., Hawkins, T.R., Xue, X., Demeke, B., Shuster, W., 2015. Comparing green and grey infrastructure using life cycle cost and environmental impact: a rain garden case study in Cincinnati, OH. JAWRA J. Am. Water Resour. Assoc. 51, 1342–1360. http://dx.doi.org/10.1111/1752-1688.12320.
Virk, G., Jansz, A., Mavrogianni, A., Mylona, A., Stocker, J., Davies, M., 2015. Microclimatic effects of green and cool roofs in London and their impacts on energy use for a typical office building. Energy Build. 88, 214–228. http://dx.doi.org/10.1016/j.enbuild.2014.11.039.
Wang, R., Eckelman, M.J., Zimmerman, J.B., 2013. Consequential environmental and economic life cycle assessment of green and gray stormwater infrastructures for combined sewer systems. Environmental Science & Technology 47 (19), 11189–11198.
William, R., Garg, J., Stillwell, A.S., 2017. A game theory analysis of green infrastructure stormwater management policies. Water Resources Research 53 (9), 8003–8019.
William, R., Stillwell, A.S., 2017. Use of fragility curves to evaluate the performance of green roofs. J. Sustain. Water Built. Environ. 3 (4). http://doi.org/https://doi.org/10.1061/JSWBAY.0000831.
William, R., Goodwell, A., Richardson, M., Le, P.V.V., Kumar, P., Stillwell, A.S., 2016. An environmental cost-benefit analysis of alternative green roofing strategies. Ecol. Eng. 95, 1–9. http://dx.doi.org/10.1016/j.ecoleng.2016.06.091.
Willows, R., Connell, R., 2003. Climate Adaptation: Risk, Uncertainty and Decision-making. Oxford, UK. Retrieved from. http://www.ukcip.org.uk/wp-content/PDFs/UKCIP-Risk-framework.pdf.
Wolch, J.R., Byrne, J., Newell, J.P., 2014. Urban green space, public health, and environmental justice: the challenge of making cities "just green enough.". Landsc. Urban Plan. 125, 234–244. http://dx.doi.org/10.1016/j.landurbplan.2014.01.017.
Zinger, Y., Blecken, G.T., Fletcher, T.D., Viklander, M., Deletić, A., 2013. Optimising nitrogen removal in existing stormwater biofilters: benefits and tradeoffs of a retrofitted saturated zone. Ecol. Eng. 51, 75–82. http://dx.doi.org/10.1016/j.ecoleng.2012.12.007.