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Barrier identification framework for the implementation of blue and green infrastructures

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ABSTRACT

Blue-green infrastructure (BGI) is becoming a more popular means of dealing with climate change and climate change-related events. However, as the concept of BGI is relatively new, many urban and rural planners are unfamiliar with the barriers they may face during the lifecycle of a BGI project. As a result, some have been hesitant to adopt BGI solutions. The literature has unveiled many of the barriers that inhibit the successful development of BGI, however, this information has yet to be presented in a manner that allows for easy identification. In this paper, a systematic literature review is undertaken to develop a framework which will enable BGI planners to assess the potential threats of a BGI project throughout the project's lifecycle.

1. Introduction

Blue and green infrastructure (BGI) has been defined as "an interconnected network of waterways, wetlands, wildlife habitats, and other natural areas; greenways, parks, and other conservation lands; working farms, ranches, and forests; and wilderness and other open spaces that support species, maintain natural ecological processes, sustain air and water resources, and contribute to the health and quality of life" (Mell, 2008). The concept of a BGI is to use natural or semi-natural infrastructure to reduce the risk of harmful natural events in a manner that delivers multiple additional ecosystem services to a wide range of individuals. For example, a BGI may be used to reduce the impact of flooding events. Floodplains or wetlands can be restored at strategic sites that will store excess water preventing surges in residential or urban areas[1]. Similarly, traditional grey infrastructure such as removable flood-barriers or waterproof walls could be also constructed to ease flooding. However, restored floodplains, the BGI solution, delivers multiple additional ecosystem services that traditional grey infrastructure does not, such as water purification, increased biodiversity and increased scenic value (Opperman et al., 2010).

It is widely acknowledged that climate change-related events such as heatwaves, drought and flooding have a negative impact on urban and rural communities worldwide (Dumenu and Obeng, 2016; Gentle and Maraseni, 2012; Reckien et al., 2017; Schröter et al., 2005;Tol, 2018). Consequently, there is a strong motivation to develop means of reducing the risks associated with climate change events on infrastructures, communities and society as a whole. Although BGI solutions provide more ecosystem service benefits than grey solutions, BGI are less frequently used to reduce the negative impact of natural events (Ghofrani et al., 2017; Evans et al., 2019). This is in part due to the myriad of barriers that the process of implementing a BGI might face from the designs stage to the construction of the BGI and during the continued maintenance of the BGI.

This paper aims to identify the main barriers that may face a BGI project so that environmental agencies, communities and any other BGI planner[2] can evaluate the challenges that might be faced. This is achieved by constructing a barrier identification framework developed from a systematic review of the literature. This paper describes how this barrier identification framework was constructed, how the identified barriers might potentially affect BGI implementation and the potential

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[1] In coastal areas the restoration of kelp forests or oyster beds can have similar flood prevention effects by dampening down storm surges.

[2] Planners refers to urban or rural planners who aim to develop BGI in their area.

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applications for the framework in BGI planning and development.

The remainder of the paper is structured as follows: Section 2 presents the systematic literature review and the barrier identification framework. In Section 3, each identified barrier is briefly described and discussed in terms of how they may affect the development or efficiency of a BGI project. Section 4 presents the applications of the framework and some of its limitations. The paper concludes with Section 5, which gives a summary of the paper and discuss some of the intended future work using the framework.

2. Barrier identification framework

The barrier identification framework (Table 2) lists the barriers identified from the literature that affect the development, construction or maintenance of BGI. By presenting the barriers other BGI projects have encountered, decision makers will be able to foresee many of the barriers their projects may face throughout the BGI's lifecycle. It may also allow for meaningful comparison across projects in terms of their viability across their life cycle.

The list of barriers has been categorised and condensed to make the framework of practical use to BGI planners. The categorisation of the framework allows it to be tailored to the user's area of expertise as not all planners will have the required knowledge to foresee certain barriers. When using the framework more information may be needed than whether the barrier exists or not. As a consequence, it is suggested that a threat level is assigned to each barrier. The threat level indicates the probability of facing the barrier and how difficult it may be to overcome the identified barrier. Suggested threat levels are none, low, moderate or high. Low level threat refer to threats that are easily dealt with, medium level threats refer to threats that may require some level of reworking of the BGI project in order ameliorate them and high level threats are extreme enough that careful consideration needs to be given to the continuation of the project.

If a barrier had a low probability of occurring but would be quite harmful to the project the user may rate the threat level as moderate. If on the other hand a barrier is almost certain to be encountered but can be easily fixed, then the user may choose to set the threat level as low. To determine the likelihood of encountering a barrier and how debilitating the barrier would be, expert opinion should be used. If the framework is being used to compare projects, it may be sufficient to use the opinions of local managers, engineers and policy makers. However, it is strongly recommended that all relevant stakeholders be involved at the earliest stage of a BGI project.

In relation to the low, medium and high probability of encountering a barrier, low probability refers to events that could happen but are very unlikely. Medium probability refers to events that have a good change of occurring, as such serious considerations must be given to the eventuality that the event will occur. High probability events are so probable that they should be treated as something that will occur.

2.1. Literature review procedure

To construct the barrier identification framework a systematic literature review was conducted using the Scopus search engine in December of 2019. Scopus was chosen due to its wider coverage compared to other academic search engines (Yang and Meho, 2006). The terms "green infrastructure" or "blue infrastructure" were combined with the words "barrier", "challenge" or "obstacle" to search the "title", "keywords" and "abstract" fields of the literature. The terms "green infrastructure" (GI) and "blue infrastructure" (BI) were used as these terms capture many of the variants used to describe BGI e.g. green infrastructure, green and blue infrastructure, blue-green infrastructure networks, etc[3]. Although the concepts of BI and GI are distinct from each other and from the concept of BGI, we have included all three in our search criteria and literature review. A BGI is an interconnected network of BI and GI, it should then follow that the barriers affecting BI and GI would also affect a BGI. However, BGI may have additional barriers not found in BI or GI alone. During the literature review process, we also found that the types of infrastructures that some may refer to as BGI are referred to as GI. This made it difficult not to include the term GI and still present a complete literature review of the barriers facing infrastructure which could be termed BGI.

This search yielded 535 results. Conference papers were removed leaving only peer-reviewed articles. We were not able to locate an additional 23 papers. Following this, the abstracts of the remaining 383 papers were read.

Literature reviews were removed as well as articles that did not demonstrate, in the abstract, that they would present barriers associated with BGI. If it was unclear as to whether or not some portion of the article would be dedicated to barriers, a scan of the article was undertaken. Articles that were focused on very specific aspects of BGI development were also removed e.g. mapping of a BGI or the use of a particular management strategy to improve interagency work in a BGI. This was done as the barriers described in these articles are overly specific and are of little use to many BGI practitioners. Following this, 84 articles were thoroughly read. However, only 40 were deemed appropriate for the current study. Table A3 in the appendix presents the following information for all the reviewed papers: the author/authors, the type of infrastructure discussed in the paper, how their data was collected (this includes whether the data was collected from a case study), the geographic region of the study and whether the study was in an urban, peri-urban or rural. We aimed to produce as much information as possible about the infrastructure type. However, many studies in Table A3 are listed as GI or BGI. In these papers the authors were looking at the general concept of BGI or GI as opposed to any individual infrastructure. They were concerned with how stakeholders view these infrastructures in a more general sense.

Some additional papers have been added to the literature review that were not found using the search terms previously noted. These papers were added to flesh out some of the biophysical and funding related barriers. From the reviewed literature, an extensive list of 56 potential barriers to the development of a BGI has been created. These barriers are listed in Table 1. Table A1 in the appendix presents a reference list for each barrier. For those interested in looking more closely at specific barriers, they can cross reference Table A1 and Table A3 (both in the appendix) to see how barriers have been discussed from different sources.

2.2. Barrier categorisation

In order to categorise the barriers, the literature was examined to determine what broader themes the barriers relate to. The themes were then used to produce categories for the barriers. The five[4] categories selected are: institutional and governance (I&G), socio-cultural (SC), knowledge (K), technical and biophysical (B), and funding and markets (F&M). Descriptions of the categories are given in the review of barriers section of his paper.

Following the selection of the categories, the context and description of each barrier, from its source/sources, was used to determine the

[3] Interested readers may also wish to read Ershad Sarabi et al. (2019) who provide a systematic review of the closely related topic of nature-based solutions and Rowcroft et al. (2011) who present barriers to establishing systems of payments for ecosystem services.

[4] Other barrier categories like socio-economic (SE) and legislative (L) were considered but each of the barriers fit more neatly into one of the other categories.

Table 1
Barrier Categorisation.

Code	Barrier			
	Barriers	Cat 1	Cat 2	Cat 3
1	Negative past experience	K	SC	
2	Low priority and/or competing priorities	I&G	SC	
3	Political leadership and champions	I&G	SC	
4	Securing effective leadership/effective future Governance	I&G	SC	
5	Legislation, regulations and governance	I&G	L	
6	How to change, need to change policy to support BGI	I&G	L	
7	Responsibilities and ownership	I&G	SC	
8	Institutional capacity and expertise	K	I&G	
9	Behaviours and culture	SC	I&G	L
10	Interagency fragmentation/Issues with partnership Working	I&G	SC	
11	Promoting interagency work	I&G	SC	
12	Poor communication and knowledge sharing	I&G	SC	K
13	Using climate science in policymaking	I&G	SC	K
14	Unclear roles	I&G		
15	Funding and costs	F&M		
16	Who pays	F&M		
17	Lack of knowledge, education and/or awareness	K	SC	
18	Lack of awareness of BGI multi-functionality	K	SC	
19	Technocratic path dependence	SC	K	
20	Uncertainty over the impacts of climate change	K	B	
21	which are the appropriate responses to climate change	K	B	
22	Public preferences, Willingness to pay for BGI	SC	K	SE
23	Lack of Community buy-in, public engagement	SC	K	SE
24	Lack of community empowerment	SC	K	SE
25	Future land use	SC	K	SE
26	Lack of landowner buy-in	SC	K	SE
27	Lack of developmental and procedural guidance	K	SC	L
28	Lack of political will	I&G	SC	K
29	No long-term vision, strategy, monitoring and/or evaluation	I&G	SC	K
30	Including climate change and environmental science in policy/design standards	I&G	SC	K
31	Keeping BGI on the political agenda	I&G	SC	K
32	Equity issue i.e. who are winners and losers	F&M	SE	
33	Understanding potential stakeholders	K	SE	
34	Lack of human resources	F&M		
35	Lack of knowledge around the impacts of grey Infrastructure	K	SC	
36	lack of maintenance standards/difficulties maintaining BGI	B		
37	Grey vested policies	I&G	SC	
38	Lack of available data	K		
39	Physical characteristics of the site/sites	B		
40	Lack of available space	B		
41	Physical science, engineering uncertainties	B		
42	Uncertainty over future infrastructure and maintenance requirements	B	F&M	
43	Uncertainty over performance and cost	B	F&M	
44	Impacts of natural hazards arising from BGI	B		
45	Retrofitting grey infrastructure	B		
46	Urban morphology	B		
47	Impact on existing ecosystems	B		
48	Construction length, Length of time to benefits	B	K	
49	Lack of identifiable examples in a geographically similar area	K		
50	Identifying and quantifying, monetising the multiple benefits	F&M	K	
51	Monitoring and Control	B	I&G	
52	Lack of financial Incentives e.g. government subsidies	F&M		
53	Transaction Cost	F&M		
54	Price Setting	F&M	K	
55	Lack of Additionality	F&M		
56	Free rider problem	F&M	SC	

I&G indicates institutional and governance, SC indicates socio-cultural, K indicates knowledge, B indicates technical and biophysical, and F&M indicates funding and markets.

appropriate category within which to place each barrier. Most barriers transcend a singular category, as can be seen in Table 1. In these cases, the category was chosen based on what the literature indicated was most appropriate. The most relevant category for each barrier is listed in Table 1 under the heading Cat 1. There were also cases where the literature did not give any clear indication as to how a barrier should be categorised. Expert opinion from within the EU Interreg ALICE project[5] was used to categorise these barriers. The second stage of the categorisation process was to reduce the total number of barriers. To do this, similar barriers were combined. The barrier list was reduced from the 56 presented in Table 1 to the 25 presented in Table 2. Table A2, in the appendix, displays the 25 barriers from the framework with the codes presented in the first column of Table 1, so the interested reader can follow the process of combining the barriers.

3. BGI barriers

BGI can be an effective tool in reducing the risk of harmful natural events while at the same time tackling the degradation of natural resources that adversely affect the delivery of ecosystem services and, by extension, human wellbeing. However, there are a range of barriers that can impede the successful implementation of BGI and thereby reduce their potential to address a number of pressing global environmental, social and economic challenges. As shown in the final column of Table 2 the planner, in consultation with stakeholders, must decides on appropriate threat level for each of the barriers identified for their specific BGI project.

With that in mind, this section provides a description of the five categories of barriers identified in Table 2. This is then followed by a discussion of the associated barriers and how these barriers may impede a BGI. This section also provides information on how each barrier affects different stakeholders associated with a BGI project.

3.1. *Institutional and governance*

Institutional and governance refers to barriers that originate from governing bodies. These barriers largely affect managerial stakeholders and those in the political or legislative realms. Barriers in this category tend to arise due to poor governance and a lack of policy development in relation to BGI.

Amongst the institutional and governance-related barriers, a lack of clear leadership is frequently cited (e.g. Borelli et al., 2018; O'Donnell et al., 2017; Romero, 2016). Clear leadership for transdisciplinary projects such as BGI requires an individual or a group of people who can transcend institutional boundaries while building trust and developing consistent relationships. This may be lacking in environmental governance circles where many ecosystem service managers are isolated from managers of different ecosystem services. Without clear leadership there is a higher likelihood of interagency fragmentation and poor communication between managerial groups (O'Donnell et al., 2017). Poor political leadership or a lack of political will can have many stifling effects on a BGI's development. Amongst these are: no motivation to improve current legislation, vested interests in grey infrastructure, and insufficient funds and resources devoted to the development and maintenance stages (Dhakal and Chevalier, 2017; Johns, 2019). A lack of political will may also deter managers from committing to BGI which have a long lifecycle, particularly if they feel that the project could be terminated at any stage during its development (Thorne et al., 2018).

A barrier linked to lack of clear leadership is poorly defined roles (Hoyle et al., 2017; Sussams et al., 2015; Thorne et al., 2018; Wihlborg

[5] The main goal of the ALICE project is to promote sustainable investments in Blue-Green Infrastructure Networks by identifying the ecosystem services benefits delivered by such networks at the terrestrial-aquatic and land-sea interface in the Atlantic Region. https://project-alice.com/alice-project/

Table 2
Barrier Identification Framework.

Barrier Type and Name	
Institutional and Governance (I&G)	**Threat Level**
Lacks clear leadership	None/Low/Medium/High
Roles and governance responsibilities	
Interagency & Interinstitutional cooperation	
Long term vision	
Legislation & regulation	
Lack of Climate Change policies	
Competing priorities	
Socio-Cultural (SC)	
Culture and behaviour	None/Low/Medium/High
Societal perception of BGI	
Community Empowerment	
Impacts on future land use	
Knowledge (K)	
Lack of general knowledge on BGI	None/Low/Medium/High
Institutional inexperience	
Lack of technical guidance	
Lack of successful stories	
Negative past experiences	
Lack of clear cause-effect relationships	
Technical and Biophysical (B)	
Onsite limitations	None/Low/Medium/High
Design challenges	
Construction challenges	
Maintenance & performance challenges	
Funding & Market (F&M)	
Lack of funding	None/Low/Medium/High
Estimating benefits and costs	
Linking providers and users	
Finding appropriate PES & MES	

Note: The planner in consultation with stakeholders decides on the relevant barriers and determines the appropriate threat levels in each case.

et al., 2019) and responsibilities or ownership of the BGI (e.g. Dhakal and Chevalier, 2017; Hoang and Fenner, 2016; Keeley et al., 2013). This often means that it is unclear what person, department or agency is responsible for different aspects of the BGI. This can lead to confusion over who is responsible for the operation and maintenance of the BGI. In some case, the consequences of unclear roles and responsibilities may be exacerbated by a lack of interagency and interinstitutional cooperation.

The interagency aspect of BGI can cause several problems which affect implementation. It has been reported that the ineffective communication between management groups can cause a myriad of issues (Johns, 2019; Thorne et al., 2018). Communication-related issues may be caused by discipline-specific language, and poor knowledge sharing between groups (Johns, 2019). Interagency issues may also lead to managers being unwilling to co-operate across disciplines and reverting to old methods (O'Donnell et al., 2017). It has been stated that the need for interdisciplinary collaboration increases with the scale of the project (Fryd et al., 2013) suggesting that the addition of new components to a BGI may make communication more difficult.

A further institutional and governance problem often faced by BGI practitioners is a lack of long-term vision and monitoring (Bissonnette et al., 2018; Dhakal and Chevalier, 2017). BGI need maintenance and investment over an extended period. This needs to be considered at the earliest stages of development. Without a forward-thinking plan long-term performance of the BGI might be hindered. Future planning may also include connectivity of additional ecosystems to an already existing BGI or legislative reforms that ensure the maintenance of a constructed BGI (Dhakal and Chevalier, 2017). Lack of long-term vision may also include an undefined method of monitoring the ongoing performance of a BGI (Angelstam et al., 2017; Dupras et al., 2015; Furlong et al., 2018; Keeley et al., 2013). When monitoring is narrowly focused on a single aspect of a BGI many of the multi-functionality benefits of a BGI are not fully realised (Keeley et al., 2013). More generally, when goals are ill-defined, and monitoring is poor it is very difficult to determine if the project is successful and worth continuing.

BGI planners may also find themselves inhibited by legislation or regulation. Dhakal and Chevalier (2017) give a robust list of the regulations and legislation that directly impede BGI in the USA and their solutions. For instance, legislation may require specific pavement materials, curb requirements or that all hard surfaces be built using certain materials. This, in effect, means that no BGI components can be built in these areas. This can also mean BGI are not legally viable or impact the connectivity of a BGI with other ecosystems, reducing the BGI's efficiency. In these instances, current legislation or regulations can perpetuate the use of grey solutions (e.g. Brudermann and Sangkakool, 2017; Dhakal and Chevalier, 2017; Dupras et al., 2015).

In addition to legislation, policy can also provide a stumbling block to efficient BGI development. A prominent issue concerning policy is the underutilisation of climate change science and modelling and environmental science in policy development (Bissonnette et al., 2018; Furlong et al., 2018; Thorne et al., 2018). As a result, policy may not reflect climate change predictions or the efficiency of BGI in comparison to grey infrastructure (Thorne et al., 2018). This in turn may under value a BGI, ultimately leading to less BGI projects. However, in recent years a concerted effort has been made to incorporate climate science and climate adaptation strategies into policy development. Examples include the European Union (EU) adaption strategy which aims to make Europe more climate resistant and the EU strategy for GI implementation which promotes investment in GI.

The final barrier in the institutional and governance category is competing priorities. BGI, like all capital projects, demand resources. Resources are however limited. As a result, BGI development can be hindered by other possible uses of these resources. This is something faced with most publicly funded projects and often assessed through cost-benefit analysis. However, BGI can underperform in such analysis due to a regular undervaluing of the multiple benefits of BGI; in particular the non-market ecosystem benefits (Keeley et al., 2013; O'Donnell et al., 2017; Thorne et al., 2018). Competing priorities may also push BGI off the political agenda for reasons such as a change in political leadership, uncertainties regarding public opinion (Thorne et al., 2018) and competing uses for the available land (Borelli et al., 2018; Dupras et al., 2015; O'Donnell et al., 2017; Wihlborg et al., 2019). One specific example of competing land uses is cited by Wihlborg et al. (2019) who asserts that the housing shortage in Sweden makes it difficult for politicians to vocalise their support for BGI when the land could be used for what is believed to be a more worthy purpose.

3.2. Socio-cultural

The second barrier category is socio-cultural. These barriers reflect embedded cultures within a stakeholder group and issues relating to their perception of BGI. These barriers may differ between stakeholder groups. For example, managers groups may be more prone to want to continue using systems they are familiar with whereas resident group may place a low value on BGI.

Socio-cultural barriers are commonly cited in the literature. However, these barriers have different impacts on different stakeholder groups. For managers, technocratic path dependence is a commonly cited barrier (Cousins, 2017; Dhakal and Chevalier, 2017; Finewood et al., 2019; Matthews et al., 2015). Technocratic path dependence has been described as processes that "are unable to shake free of their history" (David, 2001). In practice, this means that managers are unwilling to adopt the new procedures or methods that are required for the successful development of a BGI. Similarly, landowners may be unwilling to change practise they have become accustomed to or are unwilling to take part in new BGI establishing programmes (Johns, 2019). Other cultural barriers may reduce the benefits received by residents from BGI. For example, private landowners may not wish for their land, which is part of a BGI, to be used recreationally by other residents (Di Marino et al., 2019). As such, the provisioning of ecosystem services does not meet its socially optimal output.

When a group of stakeholders perceives the services that a BGI provides as being of little value the BGI has little chance of becoming a viable solution. This may be reflective of a lack of knowledge on the part of the stakeholder group but may also be due to a culturally low value being placed on the services provided by the proposed BGI (e.g. Copeland, 2013; Farrell et al., 2015; Thorne et al., 2018). In areas where there is a low perceived value for a proposed project, residents will be willing to pay less for a BGI. Even if residents place a high value on the ecosystem services, equity issues may make some individuals less willing to pay for the project (e.g. Barnhill and Smardon, 2012; Gashu et al., 2019; Williams et al., 2019). Equity issues such as who are the main beneficiaries and who is paying for the project can impede the development of an otherwise successful BGI.

In addition to a lack of community buy-in (e.g. Furlong et al., 2018; Keeley et al., 2013; Young et al., 2019), a lack of community empowerment (Bissonnette et al., 2018; Borelli et al., 2018; Finewood et al., 2019; Hoyle et al., 2017) can cause issues for the successful implementation of a BGI. In the case of community empowerment, residents may wish to become part of the BGI process but are unable to do so. In some areas, exclusion of communities or community advocates has led to an underrepresentation of the community's needs (Finewood et al., 2019). Which, in turn, may lead to inequality of the benefits received by residents from the BGI.

For landowners and managers, future or alternative land use can impact the decision to build a BGI (Borelli et al., 2018; Dupras et al., 2015; O'Donnell et al., 2017; Wihlborg et al., 2019). For instance, a landowner may wish to be flexible in production as they may foresee an increase in the selling price of some crop they could produce (Ryan et al., 2016). Joining many BGI schemes will lock the land into predefined practises that may mean that future land uses, which could be more profitable, are no longer available to them. In urban areas, similar issues may arise where alternative land uses may be perceived as being more profitable or even perceived as being more desirable for society (Wihlborg et al., 2019).

3.3. Knowledge

Knowledge barriers are issues related to different groups understanding not only of BGI but how they function and how the alternative grey infrastructure may impact biodiversity or multiple ecosystem service provisioning. Although these barriers can impact residents, they have a much larger impact on governing bodies and BGI planners.

One of the most commonly cited barriers to the implementation of a BGI is simply a lack of awareness or general knowledge of BGI (e.g. Aljoufie and Tiwari, 2015; Evans et al., 2017; Schiappacasse and Müller, 2015). This lack of awareness can range from no knowledge of BGI to limited knowledge of the co-benefits that can be achieved through a BGI. In some cases, it has been noted to stem from a lack of clarity around the concept of BGI (Sussams et al., 2015). In extreme cases, complete lack of awareness amongst managers and politicians, can mean that BGI is never suggested as a solution to environmental issues. However, even limited knowledge can have an impact on the successful proposal of a BGI. For instance, a lack of knowledge of the non-market benefits of a BGI can lead to an inaccurate cost-benefit analysis and ultimately the undervaluation of the net benefits of the BGI (Bissonnette et al., 2018; Schiappacasse and Müller, 2015; Young et al., 2019) This lack of general knowledge may lead to technocratic path-dependent behaviour when managers are unsure of the practises or methods of the purposed project (Wihlborg et al., 2019).

Institutional inexperience may manifest in several ways, particularly common is a lack of technical expertise. In some cases, technical experts will have a deep understanding of grey infrastructure methods but lack technical knowledge in BGI development (Johns, 2019; Keeley et al., 2013). There may also be an inability to acquire enough technical knowledge or hire staff with a proficient level of expertise (Keeley et al., 2013). Institutional inexperience can also extend to private enterprises being unable to participate in the development of a BGI (Li et al., 2017).

Institutional inexperience can be exacerbated by a lack of technical guidance (e.g. Dhakal and Chevalier, 2017; Gashu et al., 2019; O'Donnell et al., 2017). For more well-established grey infrastructures, planners have a catalogue of frameworks and specifications available in guidance documents. In the absence of such a catalogue, developers may be reluctant to use BGI. This combined with a perception of uncertainties around the science and engineering of BGI (Evans et al., 2017; Li et al., 2017; O'Donnell et al., 2017) and a lack of available data (Bissonnette et al., 2018; Copeland, 2013; Mguni et al., 2016) may lead to the perpetuation of old methods. Where there are guidance documents, they can be too broad or not applicable to the area of interest making the documents redundant (Li et al., 2017; Mguni et al., 2016).

Compounding the lack of technical guidance and institutional inexperience can be a lack of relative examples of working BGI (Finewood et al., 2019; Hoyle et al., 2017; Mguni et al., 2016; Thorne et al., 2018). If stakeholder groups can associate the term BGI with something that they know has worked elsewhere they may be more likely to view it as a potential solution. Even if stakeholders are aware of BGI but have not seen it working, they may view the construction and maintenance of it as a too onerous task. Success stories may help to demonstrate how a BGI can be constructed and maintained and provide valuable insight into how a BGI can work.

A less regularly stated barrier is negative past experiences (Connop et al., 2016; Gashu et al., 2019; O'Donnell et al., 2017). In part, this is due to many planners or would-be developers having no experience with BGI in the past. However, negative past experiences may also relate to bad experiences with other BGI partners. It is also possible that these negative past experiences may influence public opinion on BGI and as such decrease their perceived value.

Uncertainties about climate change events may also play a role in deciding to develop a BGI as opposed to grey infrastructure (Matthews et al., 2015; Thorne et al., 2018). In some cases, the uncertainty of how extreme climate change events will be and the scale of such events leads to inaction (Thorne et al., 2018). Also, the effects of climate change are spread over geographic areas that transcend governing boundaries making coordination and development of a BGI more difficult. However, even within a nation's own boundary, bureaucratic jurisdictions can exist which may hamper development (Johns, 2019).

3.4. Technical and biophysical

Technical and biophysical barriers are due to the characteristics of the proposed BGI site as well as design and construction issues and performance-related challenges. These barriers largely concern managers of the ecosystem services affected by the BGI or the managers of areas associated with the BGI, as well as the planners of the BGI or its components.

The onsite limitation of an area/areas that may be used for a BGI will have an impact on its effectiveness. The physical characteristics of a site (e.g. Chaffin et al., 2016; Hoang and Fenner, 2016; Hoyle et al., 2017), lack of available space (e.g. Liu and Jensen, 2018; Mguni et al., 2016; Sussams et al., 2015) and urban morphology (Brudermann and Sangkakool, 2017; Farrell et al., 2015; Lin et al., 2019; Liu and Jensen, 2018) have all been noted as impeding BGI development. Physical characteristics which have been identified as inhibiting BGI include the climatic zone of the area (Pataki et al., 2011), soil type (Furlong et al., 2018) and the slope of the terrain (Fryd et al., 2013). Lack of available space may be a more pressing issue for BGI in comparison to grey solutions as these infrastructures typically need more land cover than traditional methods (Albert et al., 2019; Pontee et al., 2016).

Design challenges related to urban environments may differ to those of rural areas. For example, structural integratory e.g. the strength of supports needed to accommodate a green roof (Angelstam et al., 2017), and subsurface infrastructure (Jim, 2003) may impact a lot of the BGI's design decisions. Uncertainties over how to design the BGI, given the physical characteristics of an area (Matthews et al., 2015) and how the BGI will interact with current ecosystems (Farrell et al., 2015) can all make it more difficult to design a BGI. There may also be uncertainties over the engineering and physical science methods that are most appropriate when constructing a BGI (e.g. Barnhill and Smardon, 2012; Hoyle et al., 2017; O'Donnell et al., 2017)

Even if it is understood how to design a BGI, construction challenges may still occur. This problem may occur when trying to integrate a BGI with already existing infrastructures (Cousins, 2017; Grant, 2012). However, in many cases, in urban areas, retrofitting grey infrastructure and combining BGI with existing grey infrastructure is more cost-efficient and effective than using BGI alone (Fryd et al., 2013).

Planners may also be uncertain about the performance of a BGI (Dhakal and Chevalier, 2017; Evans et al., 2019; Hoang and Fenner, 2016). This can be compounded by previously mentioned uncertainties over future climate change events (Matthews et al., 2015; Thorne et al., 2018) and a lack of environmental and climate change science in policy development (Bissonnette et al., 2018; Dhakal and Chevalier, 2017; Thorne et al., 2018)

Another source of uncertainty is how to maintain the BGI (e.g. Connop et al., 2016; Hoang and Fenner, 2016; Schiappacasse and Müller, 2015). In part, this is due to a lack of identifiable maintenance standards or guidelines (e.g. Barnhill and Smardon, 2012; Keeley et al., 2013; Williams et al., 2019). However, maintenance of a BGI is often a more complicated matter than maintaining a grey infrastructure. In part, this is due to the previously discussed issues of not knowing who is responsible for different elements of the BGI (Dhakal and Chevalier, 2017; Hoang and Fenner, 2016; Keeley et al., 2013) and also what is to be measured and how (e.g. Evans et al., 2017; Hamin et al., 2018; Lähde and Di Marino, 2019).

3.5. Funding & market

The final barrier type is funding and markets. These barriers relate to the problems connected with the financial aspects of the BGI implementation. These barriers affect residents, managers and landowners differently as these groups are often on the opposite side of the funding/market equation. Residents often pay for the ecosystem services a BGI provides. Landowners, on the other hand, will often receive money to allow the BGI to be built on their land or to use certain environmentally friendly practises. Landowners concerns about the BGI may, therefore, be related to profit maximisation. In addition to managing the BGI, governing bodies will often act as intermediary between the buyers and sellers in ecosystem services markets, e.g. collecting taxes to pay for a BGI programme. In this case managers may be most concerned with the best way of transferring monies from one group to another.

Funding related problems were the most common barrier cited within the literature surveyed (e.g. Di Marino et al., 2019; Dupras et al., 2015; Hoyle et al., 2017). Funding, of course, is a common issue for any publicly funded endeavour. There are always competing uses for funding and debates over which use of funds is most beneficial to society. However, there are additional issues related to BGI that are less common for grey infrastructure projects. For example, funders may restrict the use of money to certain projects or certain areas. As noted by Keeley et al. (2013), a restriction such as not being able to spend money on private land can impede the connectivity of BGI, making the project more expensive or infeasible. In part arising from competing priorities, there may be a lack of human resources devoted to BGI, with some managers suggesting that they do not have the time or their workload is already too heavy to consider the use of BGI (Wihlborg et al., 2019). It has also been stated that there are additional training and hiring requirements associated with BGI in comparison to grey infrastructure (Johns, 2019).

BGI may also differ from grey infrastructure in terms of the associated costs. Amongst the costs that differ between BGI and grey infrastructure are purchasing land, as much more land is needed for BGI (Albert et al., 2019; Pontee et al., 2016), hiring staff who have expertise in BGI and paying landowners to participate in schemes. These schemes are known as payments for ecosystem services (PES). PES have been common in agriculture through the use of agri-environmental schemes (Cullen et al., 2020; McGurk et al., 2020). Regardless of the purpose of the funding, two very important elements need to be addressed; the cost of the BGI and the benefits. The benefits to society from a BGI are often nuanced and may require multiple valuation methods to be fully estimated. For example, a BGI may improve scenic value, water quality, offer flood protection and some amount of carbon sequestering all of which require different econometric analysis to estimate their value. Authors have stated that identifying and monetising the co-benefits of a BGI is a difficult task (e.g. Connop et al., 2016; Finewood et al., 2019; Hamin et al., 2018;Qiao et al., 2019). However, as observed by Dhakal and Chevalier (2017), the multiple benefits that usually accompany the development of BGI could provide numerous sources of revenue but would require that funds go into education, awareness and outreach programs before the project even starts.

Estimating cost can also be extremely difficult, particularly for projects within rural areas. With respect to land purchases, there are two main costs associated with setting up a BGI, the first is the opportunity cost of the land to the landowner and the second is the transaction costs. Opportunity cost is defined as the loss of all other options when an alternative is chosen. What this means is that if the landowner sells their land or enters into a PES, they generally can no longer avail of the other sources of revenue the land could provide them. As a result, the landowner will have to be paid at least as much as their next best alternative for them to be willing to allow the land to be used for the BGI. The opportunity cost is largely dictated by the productivity of the land. Although, it could also include monies the landowner may receive from other development projects or less obvious considerations. For instance, a landowner may wish to be flexible in production as they may foresee an increase in the selling price of some crop they could produce (Ryan et al., 2016) or may not be willing to sell their land for a particular BGI at any price (McGurk et al., 2019). The second cost is the transaction cost. The transaction cost is the amount of money needed to make the deal between the buyer (usually resident or general population) and the seller (usually landowner or government). These costs tend to differ between developed and developing nations. For developed nations, transaction costs may include: 1) the measuring and validating of ecosystem service benefits; 2) costs in contract negotiations; 3) monitoring and enforcing ecosystem services provisions (Wunder, 2005). Transaction costs for developing nations may also include costs associated with weaker land rights, less certainly over payments, and cultural differences (Schomers and Matzdorf, 2013).

After estimating the value of a BGI to its users there still may be issues linking the users with the providers. This "linking" is often through some form of taxation, or tax credit. There are a variety of reasons that an inability to link users and providers may cause issues. It may be difficult for instance to determine who are the beneficiaries (Thorne et al., 2018), making it difficult for the providers to impose a tax on the appropriate people. Legislation may also stop the introduction of a tax without approval from certain bodies (Dhakal and Chevalier, 2017). Finally, public opinion on new charges tend to be negative. Another common issue with linking users and providers is the free-rider problem[6] (Obeng et al., 2018). When an individual (or group) cannot be excluded from the ecosystem services provided by others, they often have no incentive to pay for the service. With no means of exclusion, the potential ecosystem services provider will either have to provide the services for free or not at all. This often leads to a situation where

[6] The free-rider problem exists when those who benefit from a good or service do not pay for them.

services are not provided at the social optimal level. Examples of the ecosystem services that often encounter the free-rider problem include cleaner air, better water quality and improved scenic value.

On the provider side, issues may also arise when the "wrong" or less than optimal providers take part in the BGI scheme. For example, lack of additionality or "money for nothing" (Ferraro and Pattanayak, 2006) occurs when an individual or groups are paid to engage in activities that they would have done without payment. This social inefficiency may result in fewer funds for other projects or fewer funds to expand the current project. BGI or PES programs that do not differentiate or effectively target participants are most likely to encounter this problem (Engel et al., 2008). This adverse selection problem has been noted in the case of EU agri-environmental schemes where the farmers opting into the PES are often doing the least damage to the environment before entering the scheme and have the fewest changes to make to their farm operations (Hynes and Garvey, 2009; Murphy et al., 2011).

Finally, and closely linked to many of the other barriers in this category, is finding the appropriate mechanism of paying for the BGI. As discussed earlier, there are numerous means that the ecosystem services delivered by a BGI can be monetised (Dhakal and Chevalier, 2017). Consideration has to be given to who pays and how. For instance, a tax could be put in place to fund the development of a BGI or PES. However, it is a non-trivial matter to decide how the tax is designed. Should the heaviest users pay most, should it be a flat rate, or could it be paid through a tax on tourists and how would this affect overall tourism? Conversely, it may be more beneficial to nudge market activities towards sustainable practices. This may be achieved by helping to set up markets where sustainable practices are financially rewarded by their users, e.g. a premium paid for products from more sustainable farming practices. In these cases, individuals who benefit enough to pay more for the product can do so.

4. Application, advantages, and limitations of the barrier identification framework

The barrier identification framework can be applied in numerous ways such as in a group setting where the barriers can be discussed in a group dynamic or individually if there are concerns over more vocal individuals controlling the group. Regardless of how the framework is applied there are some steps which will ensure a smoother process. Firstly, it is advised that any workshop or other meeting using the framework should be facilitated by an individual who is able to discuss BGI. Many of the stakeholders may not have heard of the term BGI, so an introduction to the concept is vital. This introduction should include what BGI is and the development process. The facilitator should then discuss the infrastructures which the framework is going to be applied to. The stakeholders should understand where the BGI will be physically located, what it will look like and what the benefits are.

Following this the facilitator should begin to discuss how the development of a BGI could be impeded by barriers. This discussion should flow into the barrier identification framework (Table 2) which will be presented to the stakeholders. The discussion on the framework should inform the stakeholders about the barriers it contains, the categories, the threat level, what is expected of them in applying the framework and how the framework will help with future projects. In larger group settings it may be advisable to split the stakeholders into groups. In each group there must be a group leader who is familiar with each barrier, able to discuss the task of assigning threat levels and understand the BGI the framework is being applied to. Each group can also be given Table A2 which gives a one line definition for each barrier. In smaller groups the facilitator should be able to answer questions about any of the barriers, assign threat levels and the BGI they are applying the framework to.

The barrier identification framework has many positive attributes that should aid planners of BGI projects. Firstly, it enables BGI planners to identify the barriers that may be faced when developing a BGI. In many cases, planners of BGI, particularly those new to these types of projects, have reported that a lack of knowledge (e.g. Johns, 2019; Keeley et al., 2013; O'Donnell et al., 2017) and guidance (e.g. Copeland, 2013; Li et al., 2017; Wihlborg et al., 2019) as major issues in BGI development. Most first-time planners are ill-equipped to know what barriers they may face. This framework gives them some assistance in this respect. It gives them a clear point of reference for what barriers other BGI projects have encountered and allows the planner to consider their capacity to deal with each barrier.

The framework can also be used as a method for comparing competing BGI projects. In addition to traditional cost-benefit analysis, a framework such as the one provided here could be used to compare the non-monetary difficulties associated with a BGI. Practitioners may choose to apply decision rules such as having a threshold on the number of high-level threats, or they may wish to attribute points to each threat level for quick comparison across projects.

Another option is to combine the barrier framework with more diverse and complex participative approaches in which stakeholders' views can be qualitatively examined along with the results of this framework. The use of the framework in this manner may facilitate broader discussion, pushing urban and rural planners who may be unaware of BGI to discuss development possibilities they may not have considered before.

The framework has also been categorised to enable researchers to tailor it to the users if they feel it is necessary. For example, a manager or group of managers may have a lot of expertise on knowledge, technical and biophysical related barriers. As such, they may be able to predict which issues related to these topics pose the greatest threat to a project. On the other hand, they may be unaware of how a BGI can be funded or issues related to governance. By splitting the framework so that users with the appropriate level of knowledge are judging the threat of the barriers, the burden on those applying the barrier identification framework will be reduced, allowing more time to address the barriers they are familiar with. However, by splitting the framework it is less likely that insight from planners and managers outside of what is deemed the area of speciality will be obtained. Finally, the framework could also be used within stakeholder participatory approaches to facilitate debates about the potential benefits, constraints and possible solutions for the BGI implementation in a given locality.

The framework also has a number of limitation that users should be aware of. The framework does not aid in overcoming barriers which have been identified. Individuals who are interested in the specifics of how to address a barrier or barriers may wish to look at the literature and particular case studies to see what other authors have suggested. As mentioned in section 2.2, Table A3 (found in the appendix) was created to make this task somewhat easier. Table A3 enables the interested reader to cross reference barriers with papers from the reviewed literature. The application of the framework is also limited by the knowledge of the user. If the user assumes that a barrier is of no threat when it is in fact a high level threat to the project, the user may suggest beginning a project that will ultimately fail. This can be a very costly mistake. As such users should collect alternative data to evaluate their assumptions about potential barriers whenever possible.

5. Conclusion

BGI is increasingly being recognised as a viable means of combatting climate change and climate change-related events. However, BGI is still much less frequently used than traditional grey infrastructure. In part, this is due to a myriad of barriers that can impede a BGI's developments. This paper presents a framework that will enable its users to identify barriers that a BGI project may encounter. In doing so, a systematic review of the literature addressing barriers to the successful development and use of BGI was conducted. From this review, a framework was created to identify the threats facing BGI development, maintenance and efficiency. The framework is created in a manner that allows planners to become more informed of the possible barriers they could face when trying to introduce a new BGI. The framework allows for comparison across BGI projects, providing additional valuable information to accompany any traditional cost-benefit analysis. By understanding the difficulties that may arise in one project as opposed to another and how easily they can be addressed, project managers can assess which BGI are most likely to be successful. This, we feel, is fundamental information for the assessment of any new project and previously unprovided in the literature.

An interesting avenue for further research in the framework's development would be to facilitate managers of environmental services and potential BGI developers to apply the framework to their area. This could be done across different types of infrastructure that have different goals and across different ecosystem types in order to assess any unique issues with its use. This process would demonstrate how well the literature lines up with the actual experiences of mangers, if the managers feel some barriers are omitted and importantly how useful and usable the framework is in the field.

CRediT authorship contribution statement

John Deely: Methodology, Formal analysis, Writing - original draft. **Stephen Hynes:** Writing - review & editing, Supervision. **José Barquín:** Conceptualization, Writing - review & editing, Project administration, Funding acquisition. **Diane Burgess:** Writing - review & editing. **Graham Finney:** Writing - review & editing. **Ana Silió:** Writing - review & editing. **Jose Manuel Álvarez-Martínez:** Writing - review & editing. **Denis Bailly:** Writing - review & editing. **Johanna Ballé-Béganton:** Writing - review & editing.

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Appendix A

See Table A1,A2,A3

Table A1
Barriers Identified in the literature with Reference List.

Code	Barrier	References List
1	Negative past experiences	10, 28, 49
2	Low priority and/or competing priorities	18, 28, 31, 38, 39, 47, 49, 54, 62, 63, 65
3	Political leadership and champions	37, 41, 49, 54, 56, 63
4	Securing effective leadership/ effective future Governance	6, 54, 63
5	Legislation, regulations and governance	3, 5, 9, 10, 11, 15, 16, 21, 22, 23, 25, 27, 28, 31, 38, 40, 49, 56, 65, 69
6	How to change or need to change policy to support BGI	3, 5, 12, 15, 16, 27, 31, 38, 43, 63
7	Responsibilities and ownership	15, 33, 38, 49, 65
8	Institutional capacity and expertise	3, 6, 9, 11, 15, 16, 28, 38, 40, 41, 47, 49, 65
9	Behaviours and culture	28, 37, 49
10	Interagency fragmentation, Issues with partnership Working	3, 5, 8, 11, 12, 22, 28, 33, 37, 38, 40, 42, 49, 59, 62, 63, 65, 69
11	Promoting interagency work	3, 10, 15, 25, 33, 38, 40, 41, 63
12	Poor communication and knowledge sharing	3, 5, 6, 11, 15, 18, 21, 22, 25, 28, 34, 37, 38, 40, 42, 49, 63, 65, 69
13	Using climate science in policymaking	3, 12, 15, 23, 40, 59, 63
14	Unclear roles	34, 62, 63, 65
15	Funding and costs	2, 3, 4, 5, 7, 11, 12, 16, 18, 21, 22, 23, 28, 31, 34, 37, 38, 42, 47, 49, 54, 59, 62, 63, 65, 66
16	Who pays	2, 41, 63
17	Lack of knowledge, education and/ or awareness	2, 4, 5, 7, 9, 11, 15, 16, 28, 33, 37, 39, 40, 41, 42, 43, 49, 54, 59, 62, 63, 65
18	Lack of awareness of BGI multi-functionality	5, 59, 69
19	Technocratic path dependence	12, 15, 25, 43, 49
20	Uncertainty over the impacts of climate change	43, 63
21	Which are the appropriate responses to climate change	43, 63
22	Public preferences/perception and willingness to pay for BGI	11, 18, 23, 25, 34, 38, 40, 41, 47, 63
23	Lack of Community buy-in, public engagement	4, 5, 11, 18, 27, 34, 38, 40, 41, 42, 54, 63, 69
24	Lack of community empowerment	5, 6, 25, 34
25	Future land use	6, 18, 49, 65
26	Lack of landowner buy-in	3, 4, 5, 7, 8, 11, 15, 16, 23, 27, 28, 37, 38, 40, 42, 54, 65
27	Lack of developmental and procedural guidance	4, 5, 11, 15, 16, 28, 31, 38, 40, 42, 49, 62, 65
28	Lack of political will	18, 21, 22, 27, 34, 37, 41, 47, 56, 65
29	No long-term vision, strategy, monitoring and/or evaluation	3, 10, 18, 38, 59
30	Including climate change and environmental science in policy/ design standards	3, 5, 15, 27, 63
31	Keeping BGI on the political agenda	27, 63
32	Equity issue i.e. who are winners and losers	3, 18, 28, 47, 56, 59, 63
33	Understanding potential stakeholders or their needs	5
34	Lack of human resources	5, 9, 18, 35, 38, 42, 43
35	Lack of knowledge around the impacts of grey Infrastructure	15
36	lack of maintenance standards/ difficulties maintenance	2, 4, 28, 38, 40, 47, 49, 63, 65, 66
37	Grey vested policies	7, 15, 18, 37, 42
38	Lack of available data	5, 11, 40, 47, 69
39	Physical characteristics of the site/ sites	9, 11, 27, 33, 34, 37, 40
40	Lack of available space	12, 15, 40, 42, 47, 49, 62
41	Physical science, engineering uncertainties	4, 5, 22, 40, 49, 63
42	Uncertainty over future infrastructure and maintenance requirements	10, 15, 33, 37, 42, 49, 59, 65, 69
43	Uncertainty over performance and cost	11, 15, 16, 21, 25, 33, 37, 40, 41, 54, 62, 69
44	Impacts of natural hazards arising from BGI	7, 21, 41, 47, 54, 63
45	Retrofitting grey infrastructure	12, 31
46	Urban morphology	7, 23, 41, 42
47	Impact on existing ecosystems	23
48	Construction length, length of time to benefits	33
49	Lack of Identifiable examples in a geographically similar area	25, 34, 46, 63
50	Identifying and quantifying/ monetising the multiple benefits	3, 5, 10, 11, 12, 15, 22, 25, 32, 38, 39, 41, 43, 47, 49, 54, 63, 69
51	Monitoring and Control	3, 18, 27, 38
52	Lack of financial Incentives e.g. government subsidies	4, 8, 15, 38
53	Transaction Cost	22
54	Price setting	Not in reviewed literature
55	Lack of Additionality	Not in reviewed literature
56	Free rider problem	Not in reviewed literature

Table A2
Barrier definition for Table 2.

Barrier type & Name	Previous Codes	Barrier definition
Institutional & Governance		These barriers relate to mangers, politicians and legislation
Clear leadership	3 + 4 + 28	No individual/individuals pushing BGI agenda, no support from politicians and/ or unable to secure long term support for BGI
Roles and governance responsibilities	7 + 14	Roles of each agency or person and their responsibilities are not clearly stated from the beginning of the project/ unsure who is responsible for what
Interagency & Interinstitutional cooperation	10 + 11 + 12	Agency unwilling/unable to communicate with each other, agencies unwilling/unable to work together or other interagency issues
Long term vision (Adaptive management)	29 + 52	Life time of the project is not considered at beginning of the project, this may include unclear methods for performance monitoring or future funding needs
Legislation & regulation	5 + 6	Current legislation may impede BGI construction, may actively promote grey infrastructure and those interested may not know how to change the legislation
Lack of Climate Change policies	13 + 30	policy does not reflect changes that may/will occur due to climate change and/or scientific knowledge is not used to guide policy
Competing priorities	2 + 31	BGI seen as unimportant or less important than other options making it hard to put on/ keep on political agenda
Socio-cultural behaviour		These barriers relate to cultures and behaviours that may impede the development of BGI
Cultural Behaviour	9 + 19	Managers/Landowners/ Residents unwilling to move away from entrenched behaviours and cultures
Societal perception of BGI	22 + 23	Residents/landowners don't care about BGI or perceive their value as being low
Community Empowerment	24	Residents/landowners care but are not able to get involved
Impacts on perceived actual and future land use	25 + 26	The perception that land that will be used for BGI could now or in the future be used to generate more profit or to gain greater benefits
Knowledge status		These barriers relate to knowledge and experiences of those wishing to create/ develop a BGI
Lack of general knowledge on BGI	17 + 18	Lack of knowledge may also include not knowing/ understanding that BGI provide more benefits than their primary function
Institutional inexperience	8	Do not have sufficient resources and knowledge to develop/design/implement a BGI
Lack of successful stories	48	Unable to visit/see working examples of BGI
Negative past experiences	1	Failed past attempts at implementing BGI or poor experiences with elements of their implementation e.g. interdisciplinary work
Lack of technical guidance	27	Unsure how to implement a BGI as they do not have technical or legislative guidance
Lack of clear cause-effect relationships	20 + 21 + 35	Do not know which BGI will best tackle future climate change events or the extent of these events. May not know how grey infrastructure or the development of grey infrastructure could impact future climate change events.
Technical and Biophysical		These barriers relate to the technical ability to develop a BGI and issues related to the physical characteristics of the area that will be used (these may be specific to each BGIN project)
Onsite limitations	37 + 38 + 43	Examples include not enough room, site/sites unsuitable for BGI/BGI components, existing infrastructure incompatible with BGI or biophysical characteristics make the project too costly
Design challenges	39 + 40 + 44	Uncertainty around how to design the BGI or how they may impact existing/future structures
Construction challenges	45	Examples include whether current building can take rooftop gardens and how vegetation may impact underground wiring/ plumbing
Maintenance & performance challenges	36 + 41 + 42 + 46 + 47	Uncertainty around the performance of the BGI and how long it will take to construct, particularly in comparison to grey infrastructure. No clear standards to measure the performance of the BGI
Funding & Market		These barriers relate to financial matters of the BGI
Lack of funding	15 + 34 + 55	This includes lack of funding to develop the project and an inability to get the human capital required
Estimating benefits and costs	50 + 51	Difficulty measuring; the benefits to society, the willingness to pay by society, the cost to landowners, the cost of dealing with landowners and, consequently, how much the landowner should be paid
Linking providers and users	33 + 49 + 53 + 54	Uncertain over who the relevant stakeholders are, unable to demonstrate the benefits of the BGI to these stakeholders, funds going to stakeholders who may not add most value or individuals unwilling to pay but cannot be excluded from the benefits of the BGI
Finding appropriate PES & MES	16 + 32	Unclear as to how the project should be fund e.g. PES or MES and who should pay e.g. government or residents

Table A3
Reviewed literature.

Author	Infrastructure	Data source	Location	Area	Reference number
Aljoufie and Tiwari, 2015	GI, including green spaces	Case study: Textual data Satellite imagery, Concept mapping	Jeddah, Kingdom of Saudi Arabia	Urban	2
Angelstam et al., 2017	Ecological infrastructure	Case study: workshop	South Africa	Urban, peri-urban and rural	3
Barnhill and Smardon, 2012	GI, including rain garden, permeable pavement, rain barrels and trees curbside	Case study: Focus groups	New York, USA	Urban	4
Bissonnette et al., 2018	GI	Case study: Focus groups	Greater Montreal Area, Canada	Urban	5
Borelli et al., 2018	Agroforestry	Various	various	Urban, Peri-urban	6
Brudermann and Sangkakool, 2017	Greenroofs	Scientific literature, Qualitative interviews	Central and Northern Europe	Urban	7
Calvert et al., 2018	GI	Stakeholder workshops	England	Urban	8
Chaffin et al., 2016	SuDs, Rain gardens	Case study: Author led project	Cleveland, Ohio,USA	Urban	9
Connop et al., 2016	Various including restoration of brownfield, greenspace, green walls, SuDS	Case study X 3: Preliminary data from ongoing projects	Germany X 1 England X 2	Urban	10
Copeland, 2013	SuDS	Various	USA	Urban	11
Cousins, 2013	SuDS	Case study: Q-methodology using local stakeholders	Chicago, USA	Urban	12
Dhakal and Chevalier, 2017	SuDS	Review of relevant policy literature	Various USA cities	Urban	15
Di Marino et al., 2019	GI including green spaces	Case study X2: semi-structured interviews and review of relevant policy literature	Helsinki-Uusimaa and Järvenpää, Finland	Urban, Peri-urban and rural	16
Dupras et al., 2015	GI	Case study Semi-structured interviews	Greater Montreal Area, Canada	Urban, peri-urban and rural	18
Evans et al., 2019	BGI	Review of legislation and review of stakeholder perspectives	United Kingdom	Urban	21
Evans et al., 2017	Gi for coastal defence	Quantitative study and a modified Delphi survey	England and Wales	Urban	22
Farrell et al., 2015	GI for coastal defence and improved recreational opportunities.	Case Study: Stakeholder interviews	Dublin, Ireland	Urban	23
Finewood et al., 2019	SuDS	Case Study: semi-structured interviews	Pittsburgh,	Urban	25
Furlong et al., 2018	SuDS and urban greening	Case study: Various, examination of running project.	Melbourne, Australia	Urban	27
Gashu et al., 2019	Green spaces and forestry	Case Study X 2 Group discussion, interviews and observations	Bahir Dar and Hawassa, Ethiopia	Urban	28
Grant, 2012	GI including green space and green roofs	Report findings	United Kingdom	Urban	31
Hamin et al., 2018	GI for coastal Resiliency	Multiple surveys of stakeholders and framework analysis of four case studies	Various	Urban	32
Hoang and Fenner, 2016	SuDS and GI	Meta-analysis applied to UK governance and policy	United Kingdom	Urban	33
Hoyle et al., 2017	Urban Meadows	Experimental sites followed by semi-structured interviews	Bedford and Luton, United Kingdom	Urban	34
Johns, 2017	SuDS and GI	Case study: Policy analysis	Toronto, Canada		37
Keeley et al., 2013	SuDS	Case study X 2: Semi-structured interviews	Cleveland and Milwaukee, America	Urban	38
Lähde and Di Marino, 2019	GI	Case study X 3: Multidisciplinary collaborative process	Tampere, Vantaa and Jyväskylä, Finland	Urban	39
Li et al., 2017	SuDs “sponge city”	Case studies X 30: Various including visits to pilot cities and interviews with public	China	Urban	40
Lin et al., 2019	GI	Stakeholder Workshop	Austriala	Urban	41
Liu and Jensen, 2018	GI and SuDS	Case study X 5: Review of relevant open source documents followed by interviews.	Singapore Berlin, Germany Melbourne, Australia Philadelphia, USA Tianjin Eco-city, China	Urban	42
Matthews et al., 2015	GI	Analysis of planning systems	Ireland and England	Urban	43
	SuDS		Sub-Saharan cities	Urban	47

(continued on next page)

Table A3 (*continued*)

Author	Infrastructure	Data source	Location	Area	Reference number
Maguni et al., 2016		SWOT analysis of guides, manuals and SuDS literature			
O'Donnell et al., 2017	SuDS	Case Study Semi-structured interviews	Newcastle, England	Urban	49
Qioa et al., 2019	SuDS sustainable stormwater management (SSM)	Case study X4: Semi-structured interviews	Lund and Malmö, Sweden Xi'xian and Zhenjiang, China	Urban	54
Romero, 2016	GI	Case study X3: policy analysis	Texas, USA	Urban	56
Schiappacasse and Mülle, 2015	GI	Grey literature analysis	Various	Urban and Regional	59
Sussams et al., 2015	GI or climate change adaptation	Semi-structured interviews	United Kingdom	Urban	62
Throrne et al., 2018	BGI and SuDS for flood risk	Case study: Semi-structured interviews	Oregon, USA	Urban	63
Wihlborg et al., 2019	BGI for stormwater	Case study X 2: Semi-structured interviews	Malmö and Helsingborg, Sweden	Urban	65
Young et al., 2019		Results of a co-learning process	São Paulo, Brazil	Urban	69

The term sustainable urban drainage (SuDS) is used for all BGI based urban water management systems. "case study" in the data source column indicates that the data is derived from one or more case studies.

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