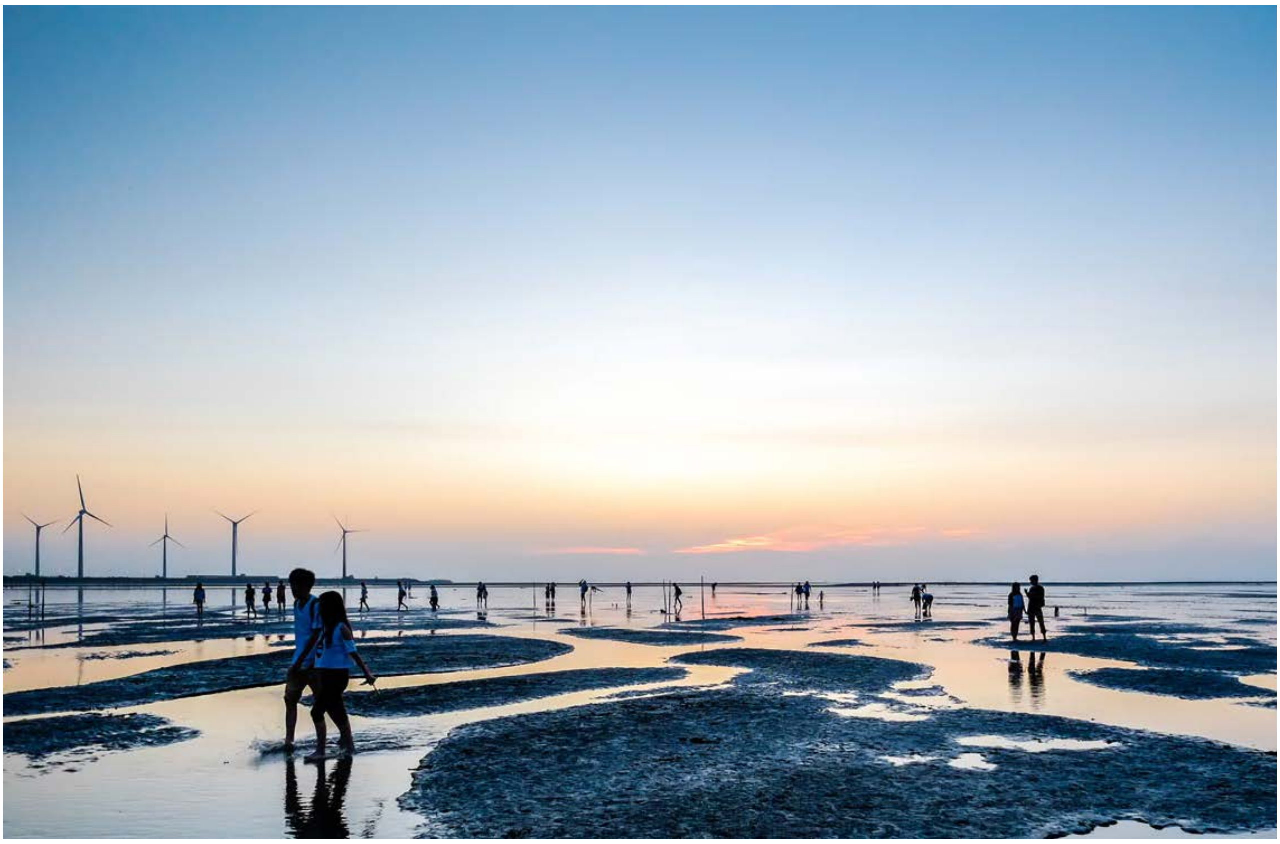
Contributions of Green Infrastructure to Enhancing Urban Resilience

Agenda Setting Scoping Studies Summary Report



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Introduction

Urban resilience is “the capacity of individuals, communities, institutions, businesses, and systems within a city to survive, adapt, and grow, no matter what kinds of chronic stresses and acute shocks they experience” (100 Resilient Cities)[1]. With 70% of the world’s population likely to be living in cities by 2050, and with climate change making weather and natural resource distributions more volatile (i.e. more storms and droughts), building resilience into our increasingly densely populated urban environments is crucial to the safety of life and property (Ahern, 2011; Lloyd’s Register Foundation, 2015; Staddon, 2010; UNISDR, 2015). Cities around the world are more and more vulnerable as a consequence of rapid urbanization, rapid expansion of complex infrastructure (especially in the post-WW2 era), and changes in climate (Lade, Fullen, Oloke, Subedi, & Booth, 2014; Petroski, 2016). According to UNISDR, 2015:

…disasters have continued to exact a heavy toll and, as a result, the well-being and safety of persons, communities and countries as a whole have been affected. Over 700 thousand people have lost their lives, over 1.4 million have been injured and approximately 23 million have been made homeless as a result of disasters. Overall, more than 1.5 billion people have been affected by disasters in various ways, with women, children and people in vulnerable situations disproportionately affected. The total economic loss was more than $1.3 trillion.

Therefore, as climate change impacts threaten urban infrastructure in cities through different internal (e.g., organisational deficiencies leading to inabilities to cope) and external hazards (e.g., environmental, social, technological and economic), enhancing resilience of engineered structures, organizations and communities becomes a priority (Lloyd’s Register Foundation, 2015).

However, resilience engineering requires new approaches that take into consideration the multi-dimensional challenges that cities will likely face or are already facing (Ahern 2011). Against this backdrop, Green Infrastructure (GI) is becoming a critical part of cities’ approaches towards resilience. For the purpose of this summary report[2] we define GI as “the creative combination of natural and artificial (blue and green as well as grey) structures intended to achieve specific resilience goals (e.g., flood management, public health, etc.) with broad public support and attention to the principle of appropriate technology.” This is a somewhat unorthodox definition inasmuch as it recognises that all infrastructure, whether blue, green or grey, is essentially engineered[3] - whether its functionality is dependent on natural (ecosystem-based) or artificial (technological) processes in the Anthropocene Era, such infrastructure is now managed, planned and engineered. We must also recognise that truly resilient infrastructure can only emerge out of socially inclusive design and engineering processes – *people-centred resilience engineering*.

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[1] Retrieved from www.100resilientcities.org/resilience#/-_/ [last accessed 12 June 2017].

[2] This is a summary report, summarising the much longer Main Report and Case Studies, submitted by the UWE, Bristol led team.

[3] The Lloyd’s Register Foundation *Foresight Review of Resilience* Engineering (2014, 33) referred to these as “hybrid-engineered” systems.

GI has the potential to enhance resilience to climate change impacts in cities including flooding, increased temperatures, and drought, while also removing air pollutants, reducing energy demands, providing amenities to the residents, and mitigating climate change. Moreover, cities are increasingly focussing on the contribution of GI to *socio-economic resilience*, on citizens' empowerment (particularly women, children and disadvantaged communities), and on improving decision-making through active engagement of citizens with GI (for example, through initiatives such as Climathon[4]). A lesson of the *Pitt Review* into the English floods of summer 2007 suggested that improving infrastructural resilience will require attention also to the dimension of social resilience as well as the resilient engineering of 'things' (Pitt, 2008). In other words, resilience is not just about the structures – grey, green, grey-green, etc. – that are intentionally designed or engineered, but also how these are conceived, (co)created and integrated within complex socio-ecological-technical systems. *Resilience emerges out of the 'how' things are done as well as the 'what' things are done.*

This report aims to provide a review of GI projects in urban environments that have resulted or may result (for new or ongoing initiatives) in increased resilience and, furthermore, it aims to point out the importance of integrating considerations of inclusion, equality and fairness into all stages of the life cycle of resilient urban infrastructure.

An inclusive, people-centred approach to urban resilience

Green infrastructure can (and should) provide multiple ecosystem goods and services leading to improved technical infrastructure performance and also improved wellbeing and health (Zuniga-Teran et. al., 2017; Tzoulas et al. 2007). However, recent studies (Frantzeskaki et al. 2017; Haase et al., 2017) have argued that the evidence for the socially positive effects from GI is still relatively weak. There is however a great deal of evidence (from the literature on "environmental justice" particularly) that poorly planned GI can lead to greater social inequality, with people from disadvantaged backgrounds forced to relocate, or being locked out from enjoying the benefits of improved ecosystem services (Wolch et al., 2014; Abercrombie et al., 2008; Byrne, 2012). If we consider GI as a critical part of a wider urban resilience strategy, a critical assessment of the implications of resilience on wellbeing and social equality must apply to any planned intervention.

There are now several resilience frameworks (ARUP and the Rockefeller Foundation, USAID, UN/Disaster Resilience Scorecard, RABIT, etc.) that help to understand key drivers to resilience in the context of complex cities' dynamics. For example, the RABIT (Resilience Assessment Benchmarking and Impact Toolkit) focuses on the contribution that Information and Communication Technologies (ICTs) can make to resilience and highlights the importance of ensuring the involvement of community members in measuring resilience and identifying community priorities. The City Resilience Framework

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[4] Climathon is a global 24-hour event where citizens, students, start-ups, entrepreneurs, big thinkers and technical experts meet to come up with innovative solutions to climate challenges in cities. Retrieved from https://climathon.climate-kic.org/ [last accessed 12 June 2017].

prepared by ARUP and the Rockefeller Foundation identifies 12 indicators that differentiate a resilient city from a non-resilient city (ARUP & The Rockefeller Foundation 2015).

However, there is still only a limited availability of robust tools for specific assessment of the contributory role of GI to urban resilience. In addition, more work is needed to help urban planners and engineers appreciate and incorporate social inclusiveness and appropriateness into thinking and practice – dimensions not always included in indicators frameworks.[5]

This study will explore the lack of knowledge and appreciation of the multidisciplinary challenges of implementing GI approaches to resilience around the world. Specifically, the review presented here organises key issues into five 'challenge domains':

- The 'standards challenge', linked to the identification of clear and applicable design and operation guidance/standards.
- The 'regulatory challenge', linked to the probabilistic nature of outcomes achievable through GI.
- The 'socio-economic challenge', related to the tendency for good GI to be located in richer postcodes or areas, or to be planned in a non-inclusive way.
- The 'financeability challenge', related to understanding of the different financing demands of GI.
- The 'innovation challenge', linked to short and longer-term innovations and transformative/disruptive technologies related to GI.

In light of the above, this report argues that two guiding principles should underpin any resilience strategy: inclusivity and appropriateness. Inclusive resilience aims to include all citizens that could be regarded as at risk as a result of minority group status through disability, cultural, ethnic, religious, socio-economic and psychological circumstances (definition adapted from Forlin, 2004). Appropriateness means that any (green) infrastructural project aimed at increasing a city's resilience must be tailored to local needs and capacities, rather than merely imposed from "above" or "outside". Excellent engineering is absolutely necessary but is not, by itself, sufficient to yield the needed step change in urban resilience thinking and outcomes.

The integration of both these concepts from the outset can foster a people-centred resilience approach. The benefits of such an approach is that beyond infrastructural interventions, people need to feel sufficiently informed and empowered to lead their own resilience journey and to prepare them to face foreseeable and unforeseeable contingencies and risks. Make no mistake – excellent socio-natural engineering is critical to meeting the resilience challenge, but it is not of itself sufficient. Also

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[5] In other work (Sun, Staddon and Chen, 2016, and Jepson, Staddon, et al, forthcoming) quantitative metrics-based frameworks are scrutinised, particular in terms of their reliance on third party data sets and their general inability to speak to finer levels of spatial or social resolution.

critical is strong, empirically-founded social science aimed at understanding social, cultural and behavioural factors underlying the experience and "performance" of resilience by individuals and communities (i.e. why do communities with otherwise identical infrastructure have such different resilience experiences?). And, from a normative perspective, it is of central importance that natural science, physical engineering and social science of resilience proceed from the ethical position that resilience inequality is not acceptable. Enhanced resilience for all must be our collective professional goal.

Resilience engineering and its relationship with GI

This chapter in the main report provides a quite detailed introduction to GI. Here we merely summarise that much lengthier discussion.

For the purposes of this project, we define GI as "the creative combination of natural and artificial (green + grey) structures intended to achieve specific resilience goals (e.g. flood management, public health, etc.). GI approaches identify and optimise natural and artificial systems for environmental and social gain". Some cities have recognized the value of GI and are transitioning from conventional grey infrastructure that includes *combined sewer systems* (CSS) to green infrastructure. A good example of this transition from green to grey and then back to green infrastructure is Los Angeles, California. As a result of extensive property damage from a severe flood in 1914, the state of California lined the Los Angeles River with concrete and constructed a drainage system. This complex system was engineered to remove stormwater rapidly from the city and reduce flooding; and it has done it successfully for the past century, but has created other problems. (Subramanian, 2016). One severe event highlighted the need to change stormwater management infrastructure in Los Angeles – the 1997-98 *El Niño*. During this time, some streets became swamped with rain events as small as two inches (*Los Angeles Times*, 2010). Recognizing the need to change stormwater management in this city, part of the concrete lining of the Los Angeles River has been removed in order to restore it to its natural state and function. In addition, Los Angeles implemented a green alley program of GI to mitigate stormwater runoff at the watershed scale (Tayouga & Gagné, 2016). This example shows that, as climate change exacerbates the risk of severe storm events and flooding, and as the world becomes urbanized, cities will continue to re-evaluate their traditional practices for stormwater management to face new threats and enhance resilience. GI shows promise to alleviate these threats and, at the same time, provide a more liveable environment for urban residents.

The main approaches of GI can be divided into 'front of the pipe' and 'end of the pipe'. Front of the pipe GI elements are those which slow, infiltrate, evaporate and/or store stormwater close to its source; whereas end of the pipe elements are basically *constructed wetlands* that are used to treat municipal and industrial wastewater, sometimes as a secondary treatment or as a polishing step of the treatment process used, for example, to treat combined sewer overflow (CSO) (Levy et al., 2014). According to Liu and colleagues (2016), best management practices such as large-scale retention ponds and wetland basins (or constructed wetlands) are used at the outlet of drainage areas – or at the end of the pipe. End of the pipe GI systems are relatively rare for CSOs management around the world. Levy et al. (2014) found only four CSO treatment wetlands in the US including three in Indiana and one in New York state. However, in Europe, end of the pipe GI for CSO management appears to be more common, especially in Germany. Front of the pipe GI elements are the most common elements found in the literature and in practical application around the world. These are often small-scale elements that can be implemented along streets or within parcels

It is important to sensitise readers to the breadth of GI types and also the breadth of potential benefits deriving from it. Engineers and designers working at all spatial scales should be excited by the prospect of where possible letting nature provide resilience benefits, though structural changes to professional education may be necessary to help enable this to happen. In addition to developing technical knowledge of the range of GI choices and applications, good resilience engineering will also need to be linked to a new approach, one that places beneficiaries at the heart of the design lifecycle.

Key challenges of GI

GI provides multiple services and benefits and GI can create logical interdependencies to the water, food, transportation, energy, health and social systems. (e.g. GI often provides attractive and convivial meeting places - Hoang & Fenner, 2016). Benefits of GI include: decreased water demand through using rainwater harvesting, enhance water quality, removal of air pollution, removal of odour and noise, provision of habitat for species, improved aesthetics and perception of neighbourhood quality, potential food production, reduced temperatures, climate change mitigation (carbon sequestration), traffic calming, energy savings in buildings, recreational opportunities and associated public health benefits, increased social cohesion, reduced traffic, reduced stormwater management costs, provision of educational opportunities, reduced stress, and increased resilience.

Although GI provide multiple benefits, it can also have some down sides. In cities located above aquifers with low thickness, GI may cause *groundwater mounding* – or the condition when stormwater is not able to infiltrate into the aquifer and dissipate (Bhaskar et al., 2016). Another down side for the implementation of GI is that it may provide habitat for mosquitoes, which may expand the geographic distribution of vector borne diseases (Wong & Jim, 2017). This issue is present in one of our featured case studies; the Sweetwater Wetlands in Tucson, Arizona. Other potential problems derived from GI are: the accumulation of debris and pollutants, the release of volatile compounds, presence of toxic and/or invasive species, poor maintenance and crime, increased risk of wildfires, increased urban heat island effect for water bodies, health issues associated with allergens, increased load in/on buildings (e.g. from green roofs) and water-related risks, increased cost of maintenance and cleaning, and risk of tree branches falling.

Moreover, there are several barriers for the implementation of GI that can be categorized into: (a) institutional, (b) technological, and (c) perceptual. *Institutional* barriers refer to the lack of political support (some politicians are reluctant to support GI because they may lose political support from voters), rapid turnover prevents continuity of GI projects, need for collaboration (shifting from traditional grey infrastructure to GI requires collaborative action), lack of coordination between government agencies and non-profit organizations, mismatch between boundaries and scale of ecosystem services, and the interdisciplinary nature of GI that requires interdisciplinary policies. *Technological* barriers include maintenance (lack of maintenance can reduce effectiveness), deficiency of data (it is difficult to quantify GI benefits), insufficient technical knowledge and experience, reluctance to change engineering practices, and difficulties with irrigation systems. Finally, *perceptual* barriers involve new responsibilities for individuals (people are accustomed of grey infrastructure and not paying for it; therefore, GI appears costlier and uncompetitive), poor understanding of GI benefits, budget constraints, age (older people are reluctant to adopt GI, lack of social acceptance, and education (educating the public is critical for the widespread implementation of GI). This is why inclusive participation is essential for implementation, and continued involvement is key to project success (Baptiste et al., 2015). Public engagement increases the legitimacy of political decisions because, by taking active part in its definition, the public is more likely to accept a policy (Giupponi and Sgobbi, 2008, p. 167). However, public participation is only part of the picture and political commitment of policy makers is also crucial to overcoming obstacles to the implementation of environmental policies (Bloquist and Schlager, 2005).

Specifically, the review presented in the Main Report organises key issues related to GI implementation into five “challenge domains”:

- Clear and applicable design and operation guidance/standards – the “**standards challenge**”. Lack of sufficient performance data and design standards is a major challenge/barrier for the widespread implementation of GI (Baptiste et al., 2015; Campbell et al., 2016). How are designers and engineers to know if proposed structures meet or exceed necessary performance standards? In addition, the inadequate design of GI and lack of maintenance has in some cases caused a negative perception of the usefulness of these systems (Charlesworth et al., 2014). Therefore, there is a need to develop standards for GI that are backed by empirical evidence, third party quality assurance mechanisms and capacity building.

- Regulatory challenges linked to the probabilistic nature of outcomes achievable through GI – the “**regulatory challenge**”. In some cities and even countries, GI implementation starts as a grassroots movement that scales up until it becomes relatively common practice, and perhaps also policy (e.g. Buildings Research Establishmetn (BRE) standards in the UK and Gold Star standards in South Africa). Even though bottom up approaches may lead to policy and action, top down regulation is critical for the widespread adoption of GI best practice. Laws and policies directly affect the implementation of GI because they can mandate its adoption.

- Socio-economic issues related to the tendency for good GI to be located in richer postcodes or areas or to be planned in a non-inclusive way – the “**socio-economic challenge**”. In most cities, low-income communities have disproportionately limited access to greenspace (Hoang & Fenner, 2016). Because of all the benefits of greenspace, unequal access to these public spaces is an environmental justice issue (Smiley et al., 2016). Low income communities may be in most need of GI whilst simultaneously least able to procure it.

- Understanding of the different financing demands of GI – the “**financeability challenge**”. Because GI can reduce the risk of floods, it may be in the economic interest of cities to transition toward this stormwater management approach – but only the grounds of well-worked out finance models that address Life Cycle costs of GI. It is necessary to examine (1) whether the implementation of GI is actually cheaper than grey infrastructure; (2) the economic instruments that are used to promote GI; (3) how to quantify the economic benefit of GI; and (4) the willingness of people, communities and governments to pay. Careful attention needs to be given to new models of “value engineering” and “value capture” in building sustainable financial models to support GI.

- Short and longer-term innovations and transformative/disruptive technologies related to GI – the “**innovation challenge**”. The successful implementation of GI requires the collaboration of scientists, planners, developers, and politicians (Tayouga & Gagné, 2016). Together they can produce the knowledge, power, and location that can successfully engage stakeholders and reach individuals (Tayouga & Gagné, 2016). In some cases, innovations in GI exist in traditional ecological knowledge. There are important opportunities for innovation in urban design. Some elements of the city may play different roles and become part of the stormwater management infrastructure during extreme events (Davies & Charlesworth, 2014).

Summary of key conclusions and ways ahead

Traditional ‘grey’ infrastructure engineering has, for several generations, represented the main approach to resilience in urban infrastructure. However, persistent over-reliance on grey infrastructure locks engineers and planners into strategies that are difficult to change and that are not likely to address the need for multi-dimensional solutions to 21st century challenges. In fact, as explained in Chapter 2, over-reliance on grey infrastructure combined with impervious surfaces, and the functional morphology of contemporary cities (e.g. spatially expansive monofunctional zones of activity connected together with automobile transport networks) exacerbates erosion of waterways, degradation of ecosystems, water pollution, and flooding (Pennino et al., 2016). Furthermore, grey infrastructure bears the risk of ultimately being too costly to implement and maintain, especially in the face of climate change. This is particularly the case in developing countries, which are disproportionately vulnerable to global impacts (Ayers, 2011; UNISDR, 2015), but also in disadvantaged communities in developed countries. This means that unless urban planners find alternative and creative ways of thinking about urban infrastructure, they might have only a limited set of solutions to enhance the overall sustainability of their city and, in general, urban wellbeing.

Against this backdrop, the work summarised in our three reports highlighted the potential contribution of GI to urban resilience. In particular, we showed that GI can represent the pillar of cities’ resilience shift by providing multidimensional solutions to multidimensional challenges. In this report and through a series of case studies, we explored the main types of GI and showed examples of how they can be used to improve not only cities’ infrastructural resilience, but also communities and citizens’ resilience. In Chapter 2 we presented a brief overview of some of the main types of GI and in the Case Study report we highlighted some examples of the multidimensional benefits of GI. For example, the creation of the Sweetwater Wetlands in Tucson (Arizona) helps treat wastewater that can be used for irrigation of golf courses, parks, school fields, etc., while at the same time providing an urban wildlife habitat and a recreational space for people. The Linear Park along the Tiete River in Sao Paulo, Brazil intends to have the same multifunctionality.

One of the key benefits of GI is that it can be applied at different scales, and can cover a small area (like in the case of green-roofs) or can underpin an entire city design, as in the case of Bicester, the first official UK Eco-Town, which integrates green roofs, permeable paving, swales, filter drains, detention areas, ponds and soakways, as well as individual/community unit rainwater harvesting. Another larger-scale example is Wuhan, a ‘sponge’ city in China, which was constructed to soak up almost every raindrop and capture water for reuse and environmental benefits[6]. Moreover, GI can fall anywhere on the continuum between purely ecological infrastructure and purely grey, traditional infrastructure, thus offering enough scope to balance the willingness to enjoy the benefits of “green” elements, with the need to provide effective and efficient services to the entire population. This means

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[6] To know more about Bicester or Wuhan, see our Case study report.

that a resilience strategy that focuses on the role of GI is more adaptable not only to new and evolving challenges, but also, crucially, it can be tailored to the local context.

Nonetheless, our scoping study revealed that there is still a very limited understanding of the potential of GI in enhancing urban resilience, and, crucially, of the challenges that implementing GI brings about. In Chapter 3 we explored the key challenges in GI planning, namely:

- The ‘standards challenge’, linked to the identification of clear and applicable design and operation guidance/standards.
- The ‘regulatory challenge’, linked to the probabilistic nature of outcomes achievable through GI.
- The ‘socio-economic challenge’, related to the tendency for good GI to be located in richer postcodes or areas or to be planned in a non-inclusive way.
- The ‘financeability challenge’, related to understanding of the different financing demands of GI.
- The “innovation challenge”, relating to new developments especially in monitoring and telemetry to management system performance and also hybrid blue-green-grey approaches.

For the purposes of this report, it was important to recognise that, like grey infrastructure, GI can also be too difficult and too costly to build and maintain, and therefore can fail to deliver sustainable results, too. Different cities experience different challenges and have different resources available to handle them. Therefore, we do not think that a one-size-fits-all approach to GI infrastructure is the way forward. Rather, we put *appropriateness* as one of the two guiding principles to make sure that GI projects are sustainable for the local community.

Furthermore, for GI to be successful in enhancing cities’ resilience, it is vital that the community is “on board”. The capacity of GI to alleviate flooding is enlarged if it is implemented at the watershed scale. This means that the larger the area of GI throughout the urban matrix, the better the results in terms of flood alleviation. This is also true for many other benefits associated with GI (e.g., temperature reduction, removal of air pollution, reduction of noise). But for the widespread implementation of GI, it is critical that residents participate actively; and again, the more people, the better. For example, maintenance is key for the effective functioning of GI, and it can only be possible at the larger scale if residents take responsibility for their own yards, for example, and the city and/or private sector take care of GI projects located in the public realm. In some countries, regulation may help bring people on board. For example, in the UK, regulations mandate the management of stormwater at the parcel scale. This means that landowners in this country have the responsibility to capture stormwater that falls onto their property. These types of regulations can certainly help with the widespread adoption of GI. However, in the US, amendments to the Constitution protect property rights and it is impossible to force individual landowners into GI implementation (new development can be regulated through building codes). Moreover, water pollution at the parcel scale is considered as ‘non-point source pollution' so federal regulations that mandate clean water standards (e.g., Clean Water Act) do not apply to individual parcels. Therefore, in the U.S. case, the participation of the community is entirely voluntary. For this reason, economic instruments have been developed to promote the adoption of GI and public participation is key to the widespread adoption of this technology.

Decision-making must be informed and enriched by the local communities' knowledge of the reality and challenges of urban life. Moreover, it is important that resilience proposals enjoy broad public support through public participation. There is growing research evidence that planning decisions that consider the inputs of multiple stakeholders under uncertain and variable future scenarios are more robust than decisions based on historical conditions (Huskova et al., 2016). However, public participation can result in biased deliberation and in outcomes whose benefits are not fairly distributed among the local communities. In light of this, we take stock of the growing academic literature that problematises public participation processes (Ayers, 2011). In particular, in proposing *inclusivity* as the other guiding principle to GI planning and implementation, we argue for public participation processes that do not replicate the inequalities and social/cultural barriers that characterise the wider society.

Against this backdrop, we think that the way forward is to develop synergies between the engineering community and the social sciences with the view of designing socio-technological systems and solutions that will be more robust in the face of climate change and other challenges; more efficient; will provide multidimensional benefits and that will be more likely to place beneficiaries at the heart of the designing lifecycle, thus also contributing to alleviate environmental justice issues (Levy et al. 2014). In order to achieve this, however, it will be necessary to act upon both current professional practice and educational paths. The Resilience Shift needs to be supported by coherent university models that take on board the importance of considering the ecological and social dimension of plans and projects as well as the technical aspects.

In sum, we propose that the future focus of resilience engineering research should be on:

1. How to make the most of existing grey infrastructure and on how to make the most of existing green capital and green capital potential.
2. 'What type of GI could work best in a certain context' rather than 'what constitutes perfect GI'?
3. How to better integrate new GI infrastructure with the existing urban environment.
4. How to make sure that engineers and urban planners are well equipped to integrate socio-economic and ecological considerations from the outset of the designing process and on how, potentially, to integrate their educational background accordingly.
5. How to overcome the barriers that relate to the five challenge domains that we identified in the introductory chapter of this report:

Standard Challenge	How to design more efficient GI projects; on which plant species are most efficient and what combination of plant species are recommended for small-medium-large projects; on what spatial configuration of GI projects works better (clusters vs. isolated projects) at the parcel, neighbourhood, and city scale; on what types of GI designs require less maintenance and are cheaper to implement.
Regulatory Challenge	Which legal mechanisms exist to guide GI intervention projects and how these mechanisms translate into practice; on what regulatory mechanisms can function as drivers for implementation; on what regulatory mechanisms act as barriers for implementation.
Socio-economic challenge	How can underrepresented communities be included in the greening of the city; on what challenges do poor neighbourhoods face that can be alleviated through GI projects; on how to promote the active participation of vulnerable communities in GI intervention projects.
Financeability challenge	How can funds be channelled to developing countries for transdisciplinary research projects that involve stakeholders in the planning and designing of GI; on what economic instruments exist for GI implementation and how do these translate into action; on what funding mechanisms can be used for long-term maintenance and for the monitoring of GI benefits and downsides.
Innovation challenge	What types of innovations exist and can be developed around existing GI and grey infrastructure that can guide the future planning of cities.

A particular challenge relates to capacity building in this area. Currently, there are few engineering, design or urban planning programmes that offer integrated approaches to GI. Rather, where there is provision, it tends to embedded as case study material (e.g. of street planting for local stormwater flooding abatement) or is optional. There is a need therefore to develop continued professional development, or CPD, courses on GI for urban resilience to help upskill existing professional planners, designers and engineers (in fact for everyone working in the urban resilience space). But traditional education programmes, particularly at BA/BSc/BEng levels, should enhance their technical coverage of GI approaches. Ideally all of this should be undertaken in collaboration with key professional organisations such as Royal Academy of Engineering, Royal Town Planning Institute and the Royal Geographical Society.

To conclude, in highlighting the role that GI can play in the cities' resilience shift, we strongly encourage the engineering and the social sciences communities to work together in order to develop multidisciplinary and transdisciplinary GI projects that are informed not only by technical and ecological knowledge but also by knowledge about the socio-economic and political context. We argue that the end-users should be included from the beginning of the planning process and the decision-making process should consider their particular needs as well as their local knowledge. Inclusivity in the process is essential to ensure all voices are heard and to avoid environmental and social justice issues. Finally, appropriateness of GI techniques that fit within the urban and social context is key to the long term sustainability and resilience of the urban infrastructure.

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Glossary

Adaptation	The IPCC defined adaptation as the adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities.
Anthropocene	Denotes the current geological age, viewed as the period during which human activity has been the dominant influence on climate and the environment.
Bioremediation	The use of microbes to clean up contaminated soil and groundwater.
Biofiltration	Pollution control technique that uses living material to biologically degrade pollutants
CAPEX	Capital expenditure, i.e. spend on initial build and commissioning of infrastructure
Drainage Priority Scheme	Generally sets out the preferred method of selecting which drainage system should be used.
Ecosystems Services	A perspective linked to the Millennium Ecosystems Assessment which posits that natural and engineered systems can be seen to offer four types of “service”: “provisioning”, “supporting”, “regulating” and “socio-cultural”.
Evapotranspiration	The water lost from an area through the combined effects of evaporation from the ground surface and transpiration from the vegetation.
Green Infrastructure	For the purpose of this project, we define GI as “the creative combination of natural and artificial (green + grey) structures intended to achieve specific resilience goals (e.g. flood management, public health, etc.) with broad public support and attention to the principle of appropriate technology.”
Inclusivity	inclusion in public deliberation processes of all citizens that could be regarded as at risk as a result of minority group status through disability, cultural, ethnic, religious, socio-economic and psychological circumstances (definition adapted from Forlin 2004, p. 187).
Infiltration	Flow of water from the land surface into the subsurface.
Infrastructure	The physical (natural and engineered) and organizational systems (e.g. utilities, roads, regulatory systems) needed for the operation of a society or enterprise.
Integrated Constructed Wetlands (ICWs)	Wastewater management system based on wetland infrastructure. In comparison to conventional treatment processes ICWs have minimal energy input, are low operation and maintenance (O&M), and can use low tech equipment for construction.
Mitigation	The IPCC defines mitigation as human intervention to reduce the sources or enhance the sinks of greenhouse gases.
Payments for Ecosystems Services	Refers to incentives offered to land managers in exchange for managing their land to provide some sort of ecological service. If it is possible to quantify and monetize (price) the ecosystems service, then it may be possible for beneficiaries to pay some or all of this assessed value to the land manager producing it.
OPEX	Operating expenditure, i.e. spend on ongoing operation and maintenance of infrastructure. Often neglected in infrastructure planning not using a “life cycle” approach.
Social-ecological systems	Social-ecological systems are linked systems of people and nature, emphasising that humans must be seen as a part of, not apart from, nature (Berkes and Folke, 1998).
Sustainable urban drainage systems (SuDS)	SuDS are a natural approach to managing drainage in and around properties and other developments. SuDS work by slowing and holding back the water that runs off from a site, allowing natural processes to break down

	pollutants (definition retrieved from NetRegs[7]).
Urban stream syndrome	Symptoms include a flashier hydrograph, elevated concentrations of nutrients and contaminants, altered channel morphology (especially straightening, culverting and concrete-armouring), and reduced biodiversity.
Xeriscaping	Landscaping designed specifically to improve water conservation and water efficiency

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[7] NetRegs: http://www.netregs.org.uk/