## Improving Urban City Resilience by Incorporating Smart Green Infrastructure Components

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###### Abstract

Growing numbers of modern cities are incorporating Smart Green Infrastructure (SGI) components in their urban design policies, adapting existing infrastructure systems to integrate these technological advances. Such systems increasingly demonstrate the benefits of SGI-integration to the improved mitigation of the impacts of extreme weather, but new research and investment is crucial for the continued development of these components and the requisite training for their skilled implementation, so as to future-proof our urban infrastructures with smart, green concepts that achieve long-term resilience. This paper examines how integrating smart green infrastructure components into existing and new urban infrastructure assets can improve their resilience in withstanding extreme weather effects. It explores the areas that stand to benefit and improve from SGI, and the types of components that can be easily supported by smart technologies in the short and long term. Previous research illustrates the need for smart water pricing and drainage systems, smart energy grid systems, smart transport efficiency monitoring, urban commuting sensors and pollution monitoring techniques to be incorporated and implemented across all levels to improve urban resilience and improve environmental efficiency. Although many cities now choose to implement SGI components, a certain disconnect remains between meeting both the agendas of ‘smart’ and ‘green’. More extensive research is required to target this discrepancy and facilitate their integration within mainstream infrastructures. A broad-ranging literature review of research papers, stakeholder reports, case studies and action plans provides a foundational understanding of the wider context and existing debates underpinning this paper. The paper also identifies current practices, challenges and opportunities to examine how SGI components contribute to the long-term wellbeing and sustainability of city dwellers.

**Keywords:** Green Infrastructure, Smart Infrastructure, Smart and Green Infrastructure, Urban City Resilience, Infrastructure Components

* 1. **Introduction**

The advent and impacts of new technologies and big data usage, alongside a growing body of data evidencing the benefits of their implementation, have led to increased interest in the use of Smart Green Infrastructure (SGI) components to manage issues such as storm-water, flooding, pollution and rising temperatures, as well as to improve the look and feel of cities for urban populations (Wray, 2017). Smart Green Infrastructure can be perceived as integrated infrastructure solutions where ‘smart technology’ and IT systems are combined with ‘green’ (and sometimes blue-water components) features to solve complex urban and environmental challenges.

Whilst man-made infrastructures (Grey Infrastructure) are designed to provide essential urban functions such as drainage or transport services (Liquete et al., 2015), they also hinder natural processes involving the migration of animals, the flow and filtration of water, the food chain, and plant succession etc. (Benedict et al, 2002).

In contrast, green infrastructure (GI) has been introduced in both planning theory and policy (Lennon, 2015) to incorporate wider integration across both spheres. GI typically refers to the interconnected network of multifunctional green spaces strategically planned and managed to provide a range of ecological, social, and economic benefits (Tzoulas et al., 2007; Wright, 2011). Examples of green infrastructure include green roofs, walls, permeable vegetated surfaces, green alleys and streets, urban forests, public parks, community gardens and urban wetlands (Foster et al, 2011). Scholars recognize that GI offers improvements to the health and wellbeing of urban inhabitants as well as better methods for sourcing food, reducing wind speeds, storm-water run-off, modulating ambient temperatures, efficient energy use and carbon sequestration, amongst other ecosystem service benefits (Mell, 2013; Roy et al, 2012). GI also holds potential in mitigating many of the anticipated impacts of climate change (Brown et al, 2015), providing a better conceptual framework for balancing manmade infrastructures with natural ecosystems (Wang et al, 2018).

The ‘Smart City’ agenda seeks to use technology and big data systems to assist in decision-making and creating networks for monitoring and modifying processes through the city. Smart technology in cities can contribute to smart pricing (water, energy, public transport, parking etc.) and drainage systems, smart energy grid systems, transport and communication efficiencies and urban commuting sensors. Coupled with green infrastructure ecosystems that enhance the resilience, long-term sustainability and the well being of city dwellers, these solutions have the potential to address future urban challenges.

Currently, smart and green infrastructure agendas run in parallel, but largely independently. However, the capability of smart networks to collect and monitor data on a large scale could prove crucial in identifying issues and improvements linked to the performance of GI components, bridging this gap and forming an essential tool for Smart Green City planning. This kind of real time data will help inform energy efficiency and savings, water efficiency and storage, air pollution and how to minimise pollution and improve biodiversity. Additionally, mapping areas of deficiency in and potential for green buildings will help planners, facility managers, estate managers and the construction industry to come together to upscale SGI development.

This paper explores the potential to move away from grey infrastructure solutions and work with nature and technology to help transform cities, providing significant environmental and socio-economic benefits whilst making our cities more resilient, healthier places to live. It examines how integrating Smart Green Infrastructure (SGI) components into existing and new urban infrastructure assets can improve their resilience in withstanding extreme weather effects due to climate change. The aim is to identify the infrastructure elements that are more vulnerable and can benefit from the incorporation of SGI components in improving urban resilience. It will examine how infrastructure providers can collaborate with both individuals and related agencies to boost the capabilities of infrastructure systems, greatly influencing social, economic and community resilience.

A broad-ranging literature review including research papers, government and other stakeholder reports, case studies and action plans informs the paper’s wider context. The methodology is based on both primary and secondary data sources and information captured from different case studies carried out in the UK and abroad. This study synthesizes the information gathered and these findings to identify how SGI components can mitigate the damages caused by extreme weather events, and provide an insight into how the mitigation strategies adopted through an integrated mechanism combining green infrastructure with the high-tech world can help future-proof our infrastructure systems, and protect the urban populations and biodiversity of a locality as a whole.

* 1. **Climate Change, Smart and Green Sustainable Cities**

Cities make up 2 per cent of the Earth’s total land surface and produce 70 per cent of CO2 emissions (UN Habitat, 2011). As forests areas absorb approximately 40 per cent of the CO2 produced (Gray, 2011), increasing the number of trees and plants within a city is more crucial than ever, with many cities introducing smart processes to combattheextreme weather impacts resulting from climate change (Carter, 2013 citing Songdo-South Korea; Wray, 2017 citing Bosco Verticale- Milan- Italy; Liuzhou Forest City- China; examples from California, Boston, New York, Chicago- America & Smart urban forestation projects from Switzerland, Holland, Brazil, Albania and France).

A ‘smart’ sustainable city is defined as an innovative city that uses information and communication technologies to improve quality of life, the efficiency of its urban operations and services, and competitiveness, while ensuring that the needs of present and future generations will be met with respect to economic, social and environmental aspects (ITU-T, Report, 2014). It is necessary that cities become “smarter” to respond to the numerous challenges in the 21st century, which include environmental degradation, limited resources, urban migration and climate change (Crnčević et al, 2017). In the context of climate change, green infrastructure (GI) has an important role in reducing the need for energy, providing ambient cooling effects, reducing floods at the local level, restoring local groundwater reserves, and allowing the soil to absorb acidity. ‘Smart environments’ (GD IP Directorate, 2014) description includes smart energy including renewables; ICT enabled energy grids, metering, pollution control and monitoring, the renovation of buildings and amenities, green buildings and green urban planning, as well as the efficient use and reuse of resources and resource substitution to serve the above goals. Therefore, green infrastructure planning, greening of the environment and the use of related IT contribute towards achieving climate-smart cities by means of adaptation measures and limited but still important mitigation measures (Cvejić et al., 2011).

In next generation ‘smart’ city, the monitoring of everything from traffic flow to household waste will be networked and responsive (Carter, 2013). Many large technology companies are adding robust information technology infrastructures to power emerging feedback systems. These smart-grid networks will become increasingly responsive in allocating electricity in response to demand or public transport systems that respond to congestion by allocating buses where people are congregating or changing lights automatically based on traffic patterns (Carter, 2013). Hi-tech operations centres are also needed, where public safety responses to infrastructure failures such as building collapses or flooding can be quickly identified, analysed and disseminated to both technical specialists and the general public.

* 1. **Improving Infrastructure Resilience for Climate Change**

The literature highlighted substantial amounts of research into the impact of a wide range of natural hazards, including snow, ice, rain, fog, wind and heat, on infrastructure. These studies span events of different spatial scale and magnitude and include results from a number of different countries. The increased frequency of flooding is the most significant climate change risk to UK infrastructure including transport, energy, communications and services, resulting in lengthy and expensive repairs averaging an estimated £1 billion per year in the UK (DEFRA, 2012). ‘A large number of assets (17% of railway tracks and 16% of railway stations, 9% of A-roads and motorways) are in locations which are prone to river or coastal, ground or surface flooding and it is projected that this risk will increase. Future Climate Change predications involving 4°C of global warming by the 2080s imply large increases in possible flood damage in UK. This scenario would lead the 2,400km of the UK rail network vulnerable to flooding rising by 120% by the 2080s’ (CCC, 2017a).

Rainfall intensity has repeatedly been shown to be a factor in transport disruption, reducing driver visibility, and reduced speeds. More intense rainfall will also increase sewer-flooding events. Rising sea levels of 0.5–1m by the end of the century will increase the proportion of assets vulnerable to coastal flooding. The need to realign coastal defenses in some areas in response to rising sea levels will have implications for infrastructure assets in the coastal zone, increasing their annual cost of maintenance. In order to address these major issues the government has created a long-term statutory framework for assessing and managing the risks to the UK from the changing climate. The Act requires the Government to assess the risks and opportunities relevant to the UK every five years and present a report to Parliament. As a result of these assessments priorities for further action and research have been identified (CCC, 2017b). Promoting and incorporating SGI components in urban development can contribute significantly in this process.

* 1. **Benefits of Smart Green Infrastructure Components**

Current urban infrastructure systems are expected to be robust, resilient and adaptable to changing patterns and capable of being optimised in terms of efficiency, cost, low carbon footprint and service quality. In order to face major challenges such as climate change or biodiversity loss, there must be a development of synergies between the three sustainability dimensions; socio, economic and environmental to achieve smart and green cities. Cities can benefit enormously from being ‘smart’, which involves the innovative use of emerging technologies in sensor and data management (Mair, 2015). In order to be truly sustainable, future infrastructure systems will need to be able to anticipate and be proactive to respond correctly, not only to short-term local conditions, but long-term, global phenomena such as extreme weather impacts. Much like an ecosystem, these will contain many small-scale, networked elements that serve a multitude of uses, rather than one single guiding purpose for their existence (Carter, 2013).

Green infrastructure (GI) has clear links to natural capital that refers to valuable elements of the natural environment and when managed well, can reap the wide-ranging economic benefits that natural assets provide. GI is often cost effective, resilient and capable of delivering multiple benefits and meeting objectives across social, environmental and economic themes. Incorporating well designed, managed and maintained GI into strategic infrastructure assets can improve resilience, increase its efficiency and performance and deliver improved return on investment. In relation to GI, within the process of creating climate-smart cities, the domains of ICT applications and improvements include: public space and utility services management, informing citizens and involving them in decision-making processes, the ability to perform various online activities (overlapping with economic needs) and similar. One of the applications of ICT is in the Geographic Information System (GIS), which can integrate data from various sources and therefore can be very helpful while “converting a city into a smart or green city” (Rehmat, 2016). The GIS is a computer-aided system for collecting, editing, storing, modeling and analyzing data, used for its alphanumerical and graphical presentation (Crncevic et al, 2017). Other novel technologies that promote smart and green infrastructure in cities include fibre optics, wireless sensor networks, low power sensors based on micro electro mechanical systems (MEMS), computer vision and energy harvesting (Mair, 2015).

Being in the midst of a digital revolution, big data has a hugely important part to play in the design, development and management of future smart cities. New sensor technologies are capable of producing vast amounts of new and important data to provide new understanding, streamlining and health monitoring of a nation’s city infrastructure. However, this data needs to be managed in an integrated way, and new Smart City Standards must be developed. These standards will help to develop the market for smart city products and services and how these can be used to enable cities to become smarter by continuous improvement. Transparency, privacy and data protection are other wider criteria that will have to be managed to achieve a smart city governance standard.

Besides GIS analysis making the density of the grey infrastructure visible, mapping green roofs at a small scale, surveying residents to assess and access different patterns of built-up sites or new technologies could be applied through the smart-compact-green city frameworks (Crnčević et al, 2017). Smart Planning systems will be able to share knowledge and data to strategically manage growth and innovation by interconnecting with other urban development departments, local authorities, residents and businesses. ICT, big data analytics offer the possibility to be more transparent, accountable, using resources more effectively and empowering and educating citizens through interactive platforms and applications used to engage all stakeholders in the decision making process in relation to their environment (Crnčević et al 2017, Albino et al., 2015).

These technologies have the capability to face the global challenges leading to considerably enhanced efficiencies, economies, resilience and adaptability benefiting not just the construction industry but also the wider society served by its infrastructure. Emerging technologies can also be applied to advanced health monitoring of existing critical infrastructure assets in cities to quantify and define the extent of ageing and the consequent remaining design life of infrastructure, thereby ensuring resilience and reducing the risk of failure. The latest sensor technologies can also transform the industry through a whole-life approach to achieving sustainability in construction and infrastructure in an integrated way (Mair 2015).

* 1. **Application of Smart Green Infrastructure Components and Systems**

###### Storm Water Management

Climate change impact has caused extreme weather resulting in unexpected torrential rain andone of the challenges is storm water management where buildings, roads, hard surfaces drain excessive water loads to sewer systems. The sewer systems are not able to handle large increases in the rainfall and it either ends up as an overflow into the rivers, which causes pollution, raised water levels and related flooding or backs up into basements in buildings causing severe floods. While making major investments in the city’s local sewers, many cities are recognising that building bigger pipes is not enough to solve the problem (Carter 2013). Green spaces, being covered in vegetation and soil systems, act like sponges to soak up rainwater, reduce the volume and rate of run-off and play a key role in sustainable urban water drainage. It is stated, ‘the rate of run-off for surfaces with trees and grass is estimated to be 10 to 20%, compared with 60 to 70% for ‘hard’ urban areas’ (Natural England, 2015). Incorporation of green ways, landscapes and wetlands that can absorb flood water, improve biodiversity and provide additional recreational areas for the local population and promote and develop healthy and multi-functional spaces can contribute to environmental, economic and social well being of communities. Sensors and electronic gauges that can monitor the sewer systems and alternate pipe systems can contribute to controlling storm water management. For example, urban community garden plots provide food for urban dwellers and serve as components of storm water management systems, allowing water and waste to be recycled at the smallest scale with real-time sensors telling the centralised system how much less will have to be processed downstream (Carter, 2013). Smart and intelligent processes could also include instrumentation, ultrasonic flow and level measurement, and smart data loggers for monitoring water levels.

###### Flood Management Systems

Flooding is the most significant climate change risk to UK infrastructure and assets and according to UK Climate Change Risk Assessment (2017); the number of assets exposed could double under expected changes in climate by the 2080s. The most common sources of flooding include: river flooding, coastal flooding, surface water flooding and groundwater flooding (CCC, 2017b). Rain runoffs quickly undermine structures such as dams, railroad beds, bridges, and buildings. In the future, tunnels may become more vulnerable, both because the risk of their entrances and vents flooding will be greater, and because the hydraulic pressure on the tunnel walls increases as water tables rise (Titus, 2002). Built up urban areas need to be drained to remove surface water quickly, but the impermeability of many built surfaces raises the probability of flash floods. Green roofs, green drainage options, sustainable vegetation management, water channels to improve green drainage and flood management, woodland corridors, green and open spaces incorporated in urban landscapes combined with smart sensors and valves for automated solutions, soft opening and closing vent systems that are controlled by smart technologies are applications that can be utilised in flood management systems. It has now become significant to shift from individual monitoring and prediction frameworks to smart flood prediction systems with the help of recent technological advancements. Internet of Things (IoT) is a technology that is a combination of embedded system hardware and wireless communication network which further transfers sensor data to computing device for analysis in real-time (Bande et al, 2017)

###### Costal Infrastructure Management Systems

Storm surges and rising sea levels pose a major threat to coastal infrastructure as well as cause sea erosion. Solutions will need to focus on future sea level rise driven by climate change and the infrastructure necessary to protect these cities from future flooding. Conventional infrastructure repairs have used a robust engineering approach, elevating hard floodwalls to predicted future sea levels, and strengthening levees to protect against more frequent and intense storm surges. Progressive coastal infrastructure proposals include designs relying heavily on natural wetland and “green” solutions. These can buffer and adapt to the disturbances through time, letting ecological processes respond, shift, and adjust to each intervention rather than creating stiffer, man-made armour. Building Information Modelling and other modelling and simulation techniques provide a greater understanding of how the new structures would interact with the existing environment. Robots and drones used for surveys provide data for modelling the foreshore and seabed and how they will behave in costal storm surges.

###### Urban Waste Management

Smart green management concepts can be applied to urban waste, where rather than moving water and solid waste away from human settlements they could be treated as resource flows, treated and reconnected to other essential city services. This is already implemented in some cities where wastewater has been converted into drinking water (Southern California), and is known to be potentially cleaner than snowmelt (Carter, 2013). The implementation of smart urban waste management will allow a more efficient waste collection and optimising the way in which it is performed encouraging people to produce less waste and move more towards recycling. The Internet of Things (IoT) empowers comprehensive data collection of information on a complex and more precision way than ever before. In the “Smart Urban Waste Management” application scenario garbage collection can be optimized e.g. in terms of route optimization based on fill levels. Empty bins are bypassed, full bins are emptied, and broken bins can be repaired quickly (Anwar, 2018).

###### Smart Grid Networks

With the desire to increase the use of renewable energy sources and reduce electricity consumption, smart grids and meters are implemented in UK and worldwide. In UK, Smart grids are ‘expected to enhance energy security and integration of low-carbon technologies and green technologies, and take a step further towards an affordable, low carbon energy system to reduce the overall costs for consumers’ (DfBEIS, 2014).Key ICTs elements will include sensing and monitoring technologies for power flows; digital communications infrastructure to transmit data across the grid; smart meters with in-home display to inform energy usage; coordination, control and automation systems to aggregate and process various data, and to create a highly interactive, responsive electricity grid that can maintain a demand-supply balance on a second-by-second basis. To achieve significant advantages over traditional communication technologies, smart grid also involves collaboration with Wireless Sensor Networks (WSNs). WSNs can enhance various aspects of today's electric power systems that include generation, delivery, and utilization (Goel, 2015). Wireless options are easy to implement and enjoy wide support but present security concerns that could be compromised to disable and damage the infrastructure of the system.

###### Urban Transportation

The rise of e-commerce, e-business and various on-line services have changed the way people move in a city from urban mobility to smart mobility. The rapid development of ICT and subsequent ICT-enabled transport services has huge potential to turn new urban mobility concepts into realities at an amazing speed and scale and they can help avoid or reduce the volume of motorized traffic. New business models associated with smart urban transportation systems will have to face new governance challenges in the successful transition from old urban transportation systems to more innovative, smart, urban mobility systems that are sustainable. These will also include integrated ticketing, ride sharing and peer-to- peer services, integrated scheduling, driverless vehicles, smart parking systems etc. Examples include: Zipcar, an ICT-enabled car sharing service provider in USA; the Walkable City concept (implemented in New York and other cities); smart bike sharing systems; Leap in San Francisco (an ICT-enabled on-demand transit service) and Uber (an ICT-enabled ride-sharing service) that have enabled many people to enjoy an urban lifestyle without owning a private vehicle (Fang, 2015). The long-term sustainable city concept must be to promote walking, cycling and use of public transport to create liveable healthy cities with minimum pollution and congestion.

###### Urban Recreation.

Park-like wetlands created for hurricane and flood mitigation can be incorporated as blue (water based) and green to existing infrastructure (grey) to benefit well-being of communities. Many of the drainage and storm water controlling practices, like rain gardens or green roofs, have aesthetic values which can be used for multi functional urban recreational spaces and combining these elements with smart mobility networks and functions create more accessible connections in future cities. Smart recreational areas can use technology (environmental, digital and materials) to reflect and fit within their cultural and environmental surroundings. Smart irrigation controllers for water use and maintenance, interactive play structures and areas that use multi cultural customisable software to meet community needs accessible to disabled children, energy-generating exercise equipment, automatic lawn mowers and other maintenance equipment and intelligent lighting systems that improve security (Jessup, 2018) are some of these smart and green infrastructure components that can be applied.

###### Urban Asset Management

Monitoring and feedback data systems are essential for cities aspiring to be smart and green to accurately measure conditions and respond to future scenarios. Sensors and technological controls embedded within existing retrofitted and new infrastructure components could monitor conditions and provide real-time feedback in case modifications are needed. Companies are adding robust information technology infrastructure to power these emerging feedback systems. With many achievable benefits, a convincing case is made for using sensing and data analysis to enable smarter, proactive asset management decision-making for city infrastructure. A system of sensors, platforms and applications that automatically collects, analyses and reports on data is radically changing the way stakeholders manage infrastructure assets. Being proactive, not reactive, enables maintenance, inspection and refurbishment programmes for city infrastructure assets to be developed, focusing on condition and preventive maintenance. It is essential to capture and analyse the right data at the right time for city asset management decisions to be effective (Mair, 2015).

* 1. **Conclusions**

The future proofing of cities to attain long term sustainability and combat climate change challenges will require incorporating smart and green technologies for city infrastructure that are responsive and transformative, ensuring the systems, including networks, sensors and communication channels are robustly monitored and that data is collected and reported in a way that it can be used effectively to make informed decisions. The smart networks are becoming increasingly responsive to stakeholder requirements and more research and development in areas such as the economics of climate change adaptation, metrics, systems; networks modeling, sensor technology and simulations, spatial decision tools and funding sources are needed.

Past infrastructure designs solved one particular problem for an isolated part of a larger system – water, waste or transportation. The study found that this concept has now shifted from single-function to multifunctional infrastructure systems. It is a fundamental rethink, but the networked nature of future smart green cities will allow infrastructure to cross sectors and serve many interests. There is also a need to repair and restore out- dated infrastructure in many cities, which could be used as an opportunity to incorporate smart green technology and components.

The study also found that many cities are implementing green drainage systems to reduce the run-offs that cause local flooding and incorporate sensor systems to monitor water levels in sewers and drainage pipes in storm water management. In modern flood management systems response time is reduced and actions are greatly enhanced by implementing IoT technology in real-time. BIM, Simulation and Virtual reality technology illustrate how systems can work or fail in a given extreme weather scenario providing valuable information in adapting to such events. Smart waste management systems have increased recycling and re-use independently and collectively. Smart grid networks enhance energy security and integration of low-carbon technologies and green technologies and more innovative, smart, urban mobility systems that include integrated ticketing, scheduling, smart parking systems are common to see. Monitoring and feedback data systems are essential to accurately measure conditions and respond to future scenarios and companies are adding robust information technology infrastructure to power these systems

Within contemporary urban design and planning practice it is a challenge to achieve smart and green cities due to these two agendas working independently. A coordinated approach and identification of dependencies and commonalities are needed to adapt to climate change more efficiently and to prioritise resources in achieving long-term sustainability. Innovative ICT, sensor and communication technologies are vital ingredients to the future of city infrastructure and will define the future relationship of society in terms of interaction, privacy, mobility and communication.

In order to achieve the required transformational impact, individual and collective smart and green infrastructure systems must be incorporated to development standards and regulations at strategic government policy level to achieve resilient urban futures. Widely used, user friendly, flexible modern technological systems could support more informed decision making around urban resilience setting requirements for new building developments and in designing new facilities. Joint up thinking, policies and strategies, the pooling of resources, investment in stable and robust smart green infrastructure via new design standards and codes and collaborative working appear essential to moving forward with the sustainable future city agenda.

A viable smart green infrastructure strategy will require new legislation to pave the way for new types of urban development. The real measure of its success will be bringing all stakeholders at different level into the process with a changed mindset; and the major challenge, maintaining a united approach that balances the needs of all sectors and integrates different systemic requirements to promote effective collaboration.

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