Major Research Project

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"SINKING THE CITY"

TOWARDS CARBON STORAGE AND REDUCED CO_2 EMISSIONS IN LOW-CARBON NEIGHBOURHOODS

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IN SUSTAINABLE URBANISM

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I declare that this project is entirely my own work and that ideas, data and images, as well as direct quotations drawn from elsewhere, are identified and referenced

Date: ______________ Signed: ______________

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ABSTRACT

At present, over half the world's population live in urban areas, which produce 75% of all CO_2 emissions and thus make a significant contribution to global climate change. However, it is not going to be possible to mitigate climate change through a reduction in fossil fuel use alone, especially as rapid urbanisation is occurring across the globe. Currently, government policy does not outline how low-carbon neighbourhoods will be developed, or the various scales at which this will take place, which represents a critical gap. Hence, this project aims to identify the various ways in which urban areas can be designed to store carbon and reduce CO_2 emissions at the building, street and neighbourhood scale. A design tool-kit has been created to answer the following research question: how can sustainable urban design be utilised to enhance carbon storage in urban areas and mitigate climate change? The design tool-kit has been tested on the Greenwich Millennium Village, London. This development was designed with sustainability in mind, but the application of the design tool-kit to the site has revealed that more can be done to store carbon and reduce CO_2 emissions. Ultimately, the design tool-kit can be used to improve developments around the world, and therefore tackle climate change.

INTRODUCTION

In this section, the topic of the major research project will be introduced, and the components of the research problem will be outlined. Following this, the research questions and project objectives will be listed, which will guide the rest of the project. Then, the contribution to practice will be stated in order to justify the topic. Finally, the steps of the methodology will be presented.

INTRODUCTION

The widespread burning of fossil fuels is adding a significant amount of carbon dioxide (CO_2) to the atmosphere, and as a direct result, contributing to global climate change. In 2010, total anthropogenic greenhouse gas (GHG) emissions reached 49 (±4.5) $GtCO_2$-equivalents per year (IPCC, 2014). Notably, CO_2 accounted for over three quarters of these GHG emissions (IPCC, 2014).

At present, over half the world's population live in urban areas, which produce 75% of all CO_2 emissions (IPCC, 2014). Figure 1 shows that business and industry and homes combined contribute 38% of CO_2 emissions, which suggests that current buildings are not energy efficient. In addition to this, transport contributes 24% of CO_2 emissions, which suggests that streets and neighbourhoods are not designed to encourage active transport. Clearly, there is a need for current research to focus on ways in which urban areas can be designed to reduce CO_2 emissions at various scales. However, it is not going to be possible to mitigate climate change through a reduction in fossil fuel use alone, and as rapid urbanisation is occurring across the globe, there is also a need for current research to focus on carbon storage in urban areas.

The capture of atmospheric CO_2 and subsequent storage in carbon pools is known as carbon sequestration. The largest carbon pool within the terrestrial biosphere is soil, and the second largest is vegetation (Jobbágy and Jackson, 2000). A carbon pool is referred to as a sink when it sequesters more carbon than it releases, which is the case for both soil and vegetation. These two carbon pools interact with each other, and vegetation type can influence the ability of soil to act as a carbon sink (Jobbágy and Jackson, 2000). Notably, carbon can also be stored in the structures of buildings (Churkina, 2016). Hence, both green infrastructure and buildings can be designed to enhance carbon storage and therefore contribute to climate change mitigation.

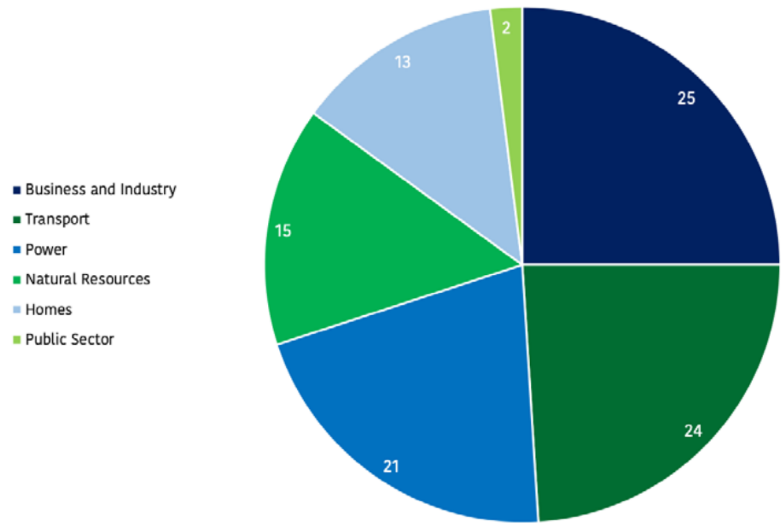

Figure 1. A breakdown of CO_2 emissions by sector in the UK (BEIS, 2017)

RESEARCH PROBLEM

LACK OF A FRAMEWORK

At present, there is no framework that sets out the best way to design urban areas for carbon storage. Consequently, new developments are not achieving their carbon storage potential. Therefore, there is a need to understand how sustainable urban design can be utilised to enhance carbon storage in urban areas.

ABSENCE OF CLEAR GUIDELINES

There are no clear guidelines that detail how to design low-carbon neighbourhoods at different scales, which is limiting the potential of these neighbourhoods to do what they were designed to do in the first place. Hence, there is a need to understand how buildings, streets and neighbourhoods can be designed to incorporate carbon storage and further reduce CO_2 emissions.

MULTIPLE ISSUES AT PLAY

It is understood that many issues related to climate change are linked. However, the design of low-carbon neighbourhoods does not take advantage of this relationship. Therefore, there is a need to understand how the design of low-carbon neighbourhoods can be optimised to tackle multiple issues related to climate change.

RESEARCH QUESTIONS

How can sustainable urban design be utilised to enhance carbon storage in urban areas and mitigate climate change?

I. How can low-carbon neighbourhoods be designed to incorporate carbon storage?

II. How can low-carbon neighbourhoods be designed to further reduce CO_2 emissions?

III. How can other issues related to climate change be addressed when designing low-carbon neighbourhoods?

PROJECT OBJECTIVES

1. To understand how low-carbon neighbourhoods can be designed to enhance carbon storage and further reduce CO_2 emissions

2. To analyse how other issues related to climate change, such as flooding, can be addressed whilst designing low-carbon neighbourhoods

3. To establish a design tool-kit that can be used to enhance carbon storage and reduce CO_2 emissions in low-carbon neighbourhoods

4. To outline design proposals that can be used to increase carbon storage and reduce CO_2 emissions at various scales in a specific urban area

CONTRIBUTION TO PRACTICE

GENERAL CONTRIBUTION TO PRACTICE

On the 27th June 2019, the government set an ambitious new target to reach net zero carbon emissions by 2050. However, government policy does not outline how low-carbon neighbourhoods will be developed, or the various scales at which this will take place, which represents a critical gap in current policy (Hodson and Marvin, 2013). Hence, there is a need for urban planners to engage with climate scientists in order to implement design measures that enhance carbon storage and reduce CO_2 emissions (Wong et al., 2011).

This project will demonstrate how low-carbon neighbourhoods can be designed to incorporate carbon storage and further reduce CO_2 emissions at different urban scales. In doing so, this project will contribute to helping the government achieve its new target through the creation of tangible solutions to a problem that is often described as intangible. The design tool-kit created in this project will be beneficial to numerous practitioners, including architects, urban designers, planners, policy makers, engineers, scientists and many more.

It is hoped that the design tool-kit created in this project can be transferred to different urban contexts, as climate change is a global problem. The transferability of the design tool-kit will not be possible without consideration of the economic, political, social, and environmental situation in the place of implementation. In respect of this, the site used for testing the design tool-kit will be thoroughly analysed to demonstrate the relevance of the local context.

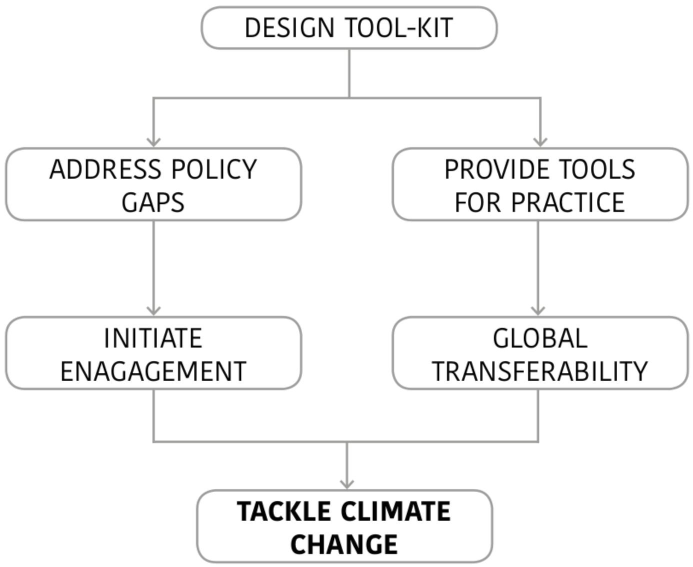

Figure 2. Progressive benefits of the design tool-kit

CONTRIBUTION TO PRACTICE

SUSTAINABLE DEVELOPMENT GOALS

The design tool-kit can be utilised to help meet the Sustainable Development Goals (SDGs) set out by the United Nations (Figure 3). In particular, this project aims to address SDG 11, which is to make cities and human settlements inclusive, safe, resilient and sustainable, and involves preparing cities for mitigation and adaptation to climate change (United Nations, 2019). In particular, the design tool-kit will illustrate how to make cities more resilient and sustainable in the face of climate change. This project also aims to address SDG 13, which is to take urgent action to combat climate change and its impacts, and involves integrating climate change measures into national policies, strategies and planning (United Nations, 2019). Notably, this project will address the current policy gap in this area of research and provide an example of how neighbourhoods can be planned in the future.

Figure 3. Sustainable Development Goals (United Nations, 2019)

METHODOLOGY

INTRODUCTION

- Introduce the topic and state the research problem
- Outline the research questions and the project objectives
- Justify the topic through detailing the project's contribution to practice

RESEARCH

- What is a low-carbon neighbourhood and why is scale important?
- Analyse how urban areas can be designed to enhance carbon storage and reduce CO_2 emissions
- Outline the relationship between the issues related to climate change
- Summarise the findings of the literature review
- Identify a range of case studies and summarise findings
- Develop a conceptual framework
- Establish a design tool-kit, including a clear set of design principles
- Outline the design objectives

APPLICATION

- Introduce the site, including a background of the site and justification of the site choice
- Conduct a site analysis, highlighting the strengths, weaknesses, opportunities and threats of the site
- Outline the design proposals at the building, street and neighbourhood scale using the design tool-kit
- Provide a summary of the interventions

CONCLUSION

- Summarise the findings of the major research project
- Highlight the strengths and weaknesses of the project
- Suggest any opportunities for future research

RESEARCH

In this section, a review of the current literature will be undertaken, covering low-carbon neighbourhoods, scale, carbon storage and methods to reduce CO_2 emissions in urban areas. Following this, a case studies review will be carried out, in which three examples of best practice in low-carbon neighbourhood design will be analysed in detail. Finally, a conceptual framework will be presented, and then the design tool-kit and design objectives will be outlined in detail.

LITERATURE REVIEW

WHAT IS A LOW-CARBON NEIGHBOURHOOD?

A low-carbon neighbourhood is defined as a neighbourhood that improves health, quality of life and resilience, empowers the community, benefits the local economy, reduces energy bills, and addresses climate change (CSE, 2018). In short, a low-carbon neighbourhood is a type of sustainable development, which is defined as a "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987). A term that is often used interchangeably with low-carbon development is sustainable neighbourhood design (Kim and Lee, 2013). However, despite the emergence of sustainable neighbourhood design, most new developments continue to facilitate unsustainable behaviour, such as driving and excessive energy use (Barton et al., 2010). Hence, the low-carbon neighbourhood seeks to tackle unsustainable behaviours through design in order to preserve urban areas for future generations.

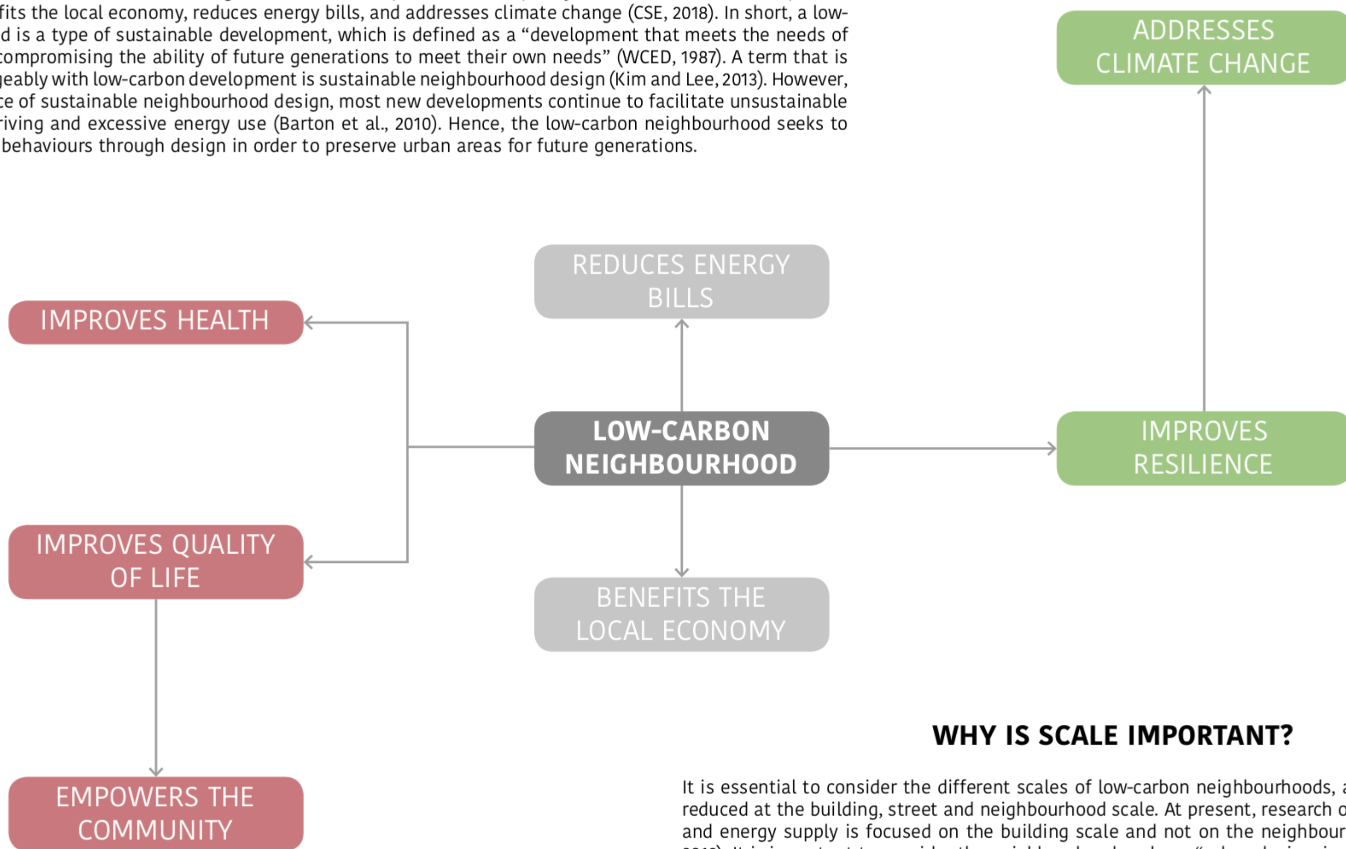

Figure 4. Benefits of a low-carbon neighbourhood (CSE, 2018).

WHY IS SCALE IMPORTANT?

It is essential to consider the different scales of low-carbon neighbourhoods, as CO_2 emissions can be reduced at the building, street and neighbourhood scale. At present, research on building performance and energy supply is focused on the building scale and not on the neighbourhood scale (Koch et al., 2012). It is important to consider the neighbourhood scale as "urban design, including the clustering of buildings and mixing of different building types within a given area, greatly affects the opportunities for and cost of district heating and cooling systems" (IPCC, 2007). Notably, energy production is often viewed at the regional scale, which is not beneficial to the management of on-site energy production (Koch et al., 2012). Clearly, there is a need to examine low-carbon neighbourhoods at different scales, in order to identify how the components of each scale interact with each other. In doing so, the mechanisms by which low-carbon neighbourhoods store carbon and reduce CO_2 emissions can be better understood.

STORING CARBON IN GREEN INFRASTRUCTURE

In many cities around the world, green space is built on during densification, which decreases the potential of urban areas to store carbon in soil and plants (Davies et al., 2011). In response to this, there has been a growing interest in green infrastructure, since both soil and plants can store a significant amount of carbon through biotic sequestration (Chen, 2015). In particular, green roofs have the potential to store a significant amount of carbon when suitably managed and designed (Jahanfar et al., 2018; Whittinghill et al., 2014).

It has been found that green roofs can control the microclimate through cooling (Park et al., 2018), and therefore mitigate the urban heat island effect (Lehmann, 2014). In addition to this, green roofs can reduce energy use (Pataki et al., 2011), improve biodiversity in the area (Bai, 2018), and provide health benefits to residents (Wolch et al., 2014). Figure 5 illustrates some of the ecosystem services and benefits of green infrastructure, which highlights the relationship between various issues related to climate change. Jahanfar et al. (2018) found that buildings with roofs designed or retrofitted with both photovoltaics and green roofs are more energy efficient and produce fewer CO_2 emissions than conventional roofs. Evidentially, green roofs provide far more benefits than just carbon storage, which makes them an attractive intervention.

There are many other forms of green infrastructure, including street trees, green walls, habitat corridors, private gardens and public parks. It has been estimated that urban areas could have a net sink of CO_2 if 80% of the area consists of green infrastructure (Nordbo et al., 2012). Hence, there is a need to green urban areas in order to tackle climate change.

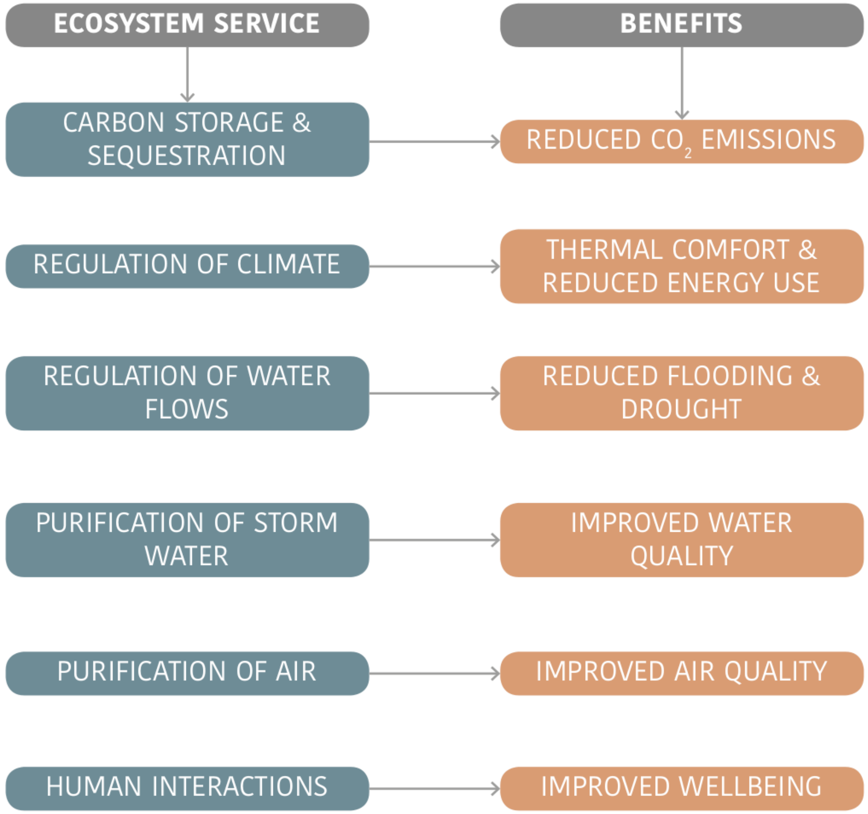

Figure 5. Ecosystem services and benefits of green infrastructure within a climate change mitigation and adaptation framework (Adapted from Demuzere et al., 2014)

STORING CARBON IN BUILDING MATERIALS

In 2010, the building sector was responsible for around 32% of energy consumption and 8.8 $GtCO_2$-equivalents (IPCC, 2014). Furthermore, together with the industry sector, the building sector contributed to 50% of GHG worldwide (IPCC, 2014). As energy demand is predicted to double, and CO_2 emissions are set to increase by 50-150% by 2050 (IPCC, 2014), there is a need to make buildings more sustainable.

In order to reduce energy consumption and thus reduce CO_2 emissions, new buildings should incorporate sustainable building materials and technologies, and existing buildings should undergo energy retrofitting (Guo et al., 2017). The use of wood-based building materials can both decrease CO_2 emissions produced during manufacturing and increase carbon storage in the structure of buildings (Freitas et al., 2018). Guo et al. (2017) found that energy consumption and CO_2 emissions in Cross-Laminated Timber (CLT) buildings are lower than that of reinforced concrete buildings. In support of this, Hafner and Schäfer (2018) state that CLT is an optimal building material for carbon storage.

In Europe, CLT is used for mid-rise residential and low-rise commercial buildings, since it is sustainable, low-cost and quick to construct (Mallo and Espinoza, 2014). The Dalston Works in Hackney, London, was constructed using CLT in order to decrease the carbon footprint of the building (Figures 6 and 7). It is estimated that the building has half the embodied carbon of a traditional concrete building (Ramboll, 2017). In addition to this, the structure stores over 2,600 tCO_2 and it has been estimated that the building will be carbon negative during the first couple of years of its life (Ramboll, 2017).

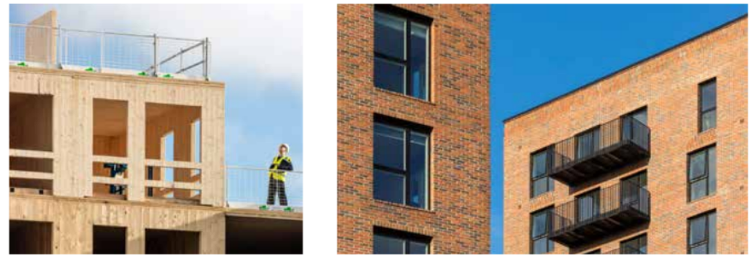

Figure 6. Stages of construction of the Dalston Works, Hackney (Waugh Thistleton Architects, 2016)

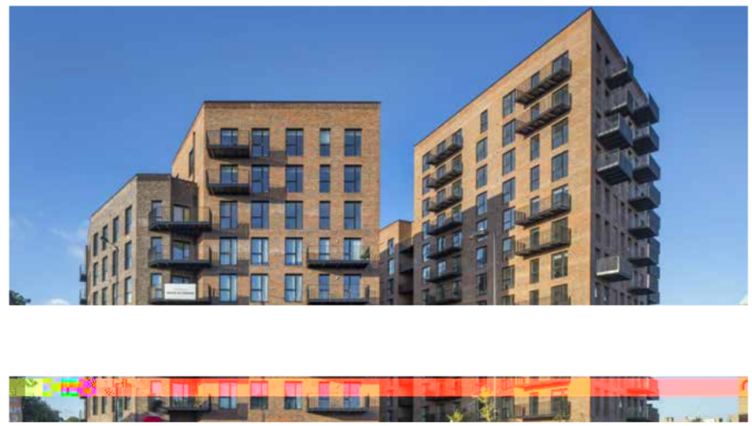

Figure 7. Dalston Works, Hackney (Ramboll, 2017)

TACKLING WATER AND CARBON

It is widely known that Sustainable Urban Drainage Systems (SUDS) provide a sustainable method of stormwater management in urban areas. Interestingly, SUDS also have the ability to store carbon.

RETROFITTING VS. NEW DEVELOPMENTS

In countries with existing building stock, high-performance retrofits should be carried out to reduce CO_2 emissions, since buildings tend to be long-lived (IPCC, 2014). Moreover, the demolition of buildings causes the release of CO_2 emissions. In the UK, domestic buildings account for 27% of CO_2 emissions (DEFRA, 2006). However, the domestic stock is heterogeneous, and so various retrofitting measures are required depending on the type of building (Jenkins, 2010). For example, a building with a cavity-wall construction requires a different type of insulation to a building with a timber frame structure (Jenkins, 2010). Still, it is possible to reduce energy use related to heating/cooling by 50-90% through retrofitting alone (IPCC, 2014). Figure 9 shows some examples of retrofitting a building. In the UK, the Green Deal encourages private firms to invest in retrofitting measures, which are financed by consumers through their energy bills (Koch et al., 2012).

THE POWER OF RENEWABLE ENERGY

The energy supply sector is the biggest contributor to global GHG emissions (IPCC, 2014). In the building sector, improvements in energy efficiency are vital for reducing indirect CO_2 emissions from electricity generation (IPCC, 2014). However, decarbonising electricity generation is the most important step to reducing CO_2 emissions (IPCC, 2014). In particular, this involves a move to decentralised energy in order to localise energy production. Figure 10 provides an example of the various components of a decentralised neighbourhood.

An important aspect of low-carbon neighbourhoods is the on-site production of energy from renewable resources, which reduces the dependence of the neighbourhood on fossil fuels (Koch et al., 2012). A number of technologies exist, including Photovoltaic Cells (PV), solar thermal collectors, heat pump systems, and wind turbines (Koch et al., 2012). However, the supply of renewable energy can be intermittent as it often depends on the climate, which is the case for solar energy and wind power (Koch et al., 2012). Still, this problem can be overcome by installing thermal storage systems in buildings and transferring excess thermal energy into a district heating network (Koch et al., 2012).

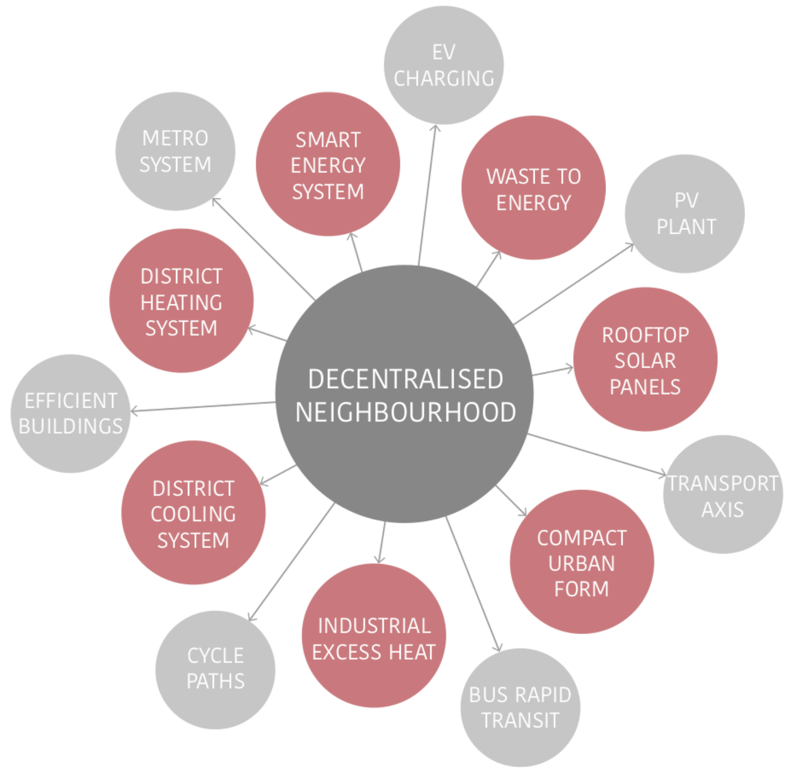

Figure 10. A system of decentralised energy (Adapted from IEA, 2017)

ACTIVE TRANSPORT FOR CLEANER CITIES

A reduction in CO_2 emissions is often difficult to achieve in the transport sector because of the poor choice of low-carbon energy carriers (IPCC, 2014). Hence, it is important that urban areas are designed to encourage active transport, which is defined as "travel between destinations by walking, cycling or other non-motorised modes" (Burke and Brown, 2007). In the UK, cycling as a form of regular travel is on the decline as people have become more car dependent and cycling marginalised (Jones, 2012). However, urban design can be utilised to encourage active transport. At the neighbourhood scale, incorporating mixed-use areas encourage residents to walk due to the provision of facilities in the immediate vicinity (Faherty and Morrissey, 2014). In addition to this, design measures such as pedestrian paths and bicycle paths make active transport easier and more enjoyable for residents. Still, the design of the built environment isn't the only factor that influences whether or not residents decide to use active transport, as attitudes and preferences also play a role (Figure 11). Ultimately, a range of causal mechanisms will be relevant in various situations at various times, which is dependent on both the attitudes and preferences of residents and the design of the built environment (Handy et al., 2006).

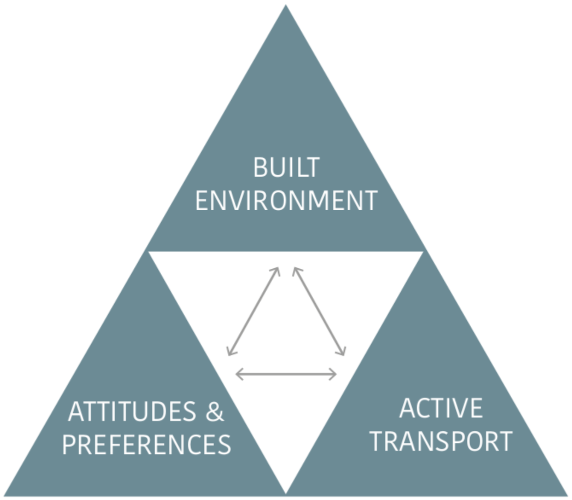

Figure 11. Conceptual model of the relationship between the built environment, active transport, and attitudes and preferences (Adapted from Handy et al., 2006)

LITERATURE REVIEW

MEASURE	FUNCTION	DESCRIPTION	QUANTIFICATION
Green Infrastructure	Store Carbon	A network of green areas that provide ecosystem services and includes green roofs, green walls, habitat corridors, private gardens and public parks	0.0308 tCO_2 per m^2 per year (Whittinghill et al., 2014)
Trees and Vegetation	Store Carbon	A range of species can store biogenic carbon, but some species are better adapted for this purpose	0.0003 tCO_2 per m^2 per year (Nowak et al., 2013)
Sustainable Materials	Store Carbon	A good example is CLT, which is a wood-based building material that can store carbon in its structure	0.0033 tCO_2 per m^3 per year (Guo et al., 2017)
SUDS	Store Carbon	A sustainable method of stormwater management, including rain gardens, bioretention basins and vegetated bioswales	0.0025 tCO_2 per m^2 per year (Kavehei et al., 2018)
Insulation	Reduce CO_2 Emissions	A common way of improving the energy efficiency of new and existing buildings	CO_2 saving of 50% (Jenkins, 2010)
Triple Glazing	Reduce CO_2 Emissions	A type of window glazing made from three panes of glass that improves the energy efficiency of new and existing buildings	CO_2 saving of 10% (Jenkins, 2010)
Renewable Energy	Reduce CO_2 Emissions	A sustainable method of generating energy, including PV cells, solar thermal collectors, heat pump systems, wind turbines and CHP plants	CO_2 saving of 44% (Hull, 2018)
Rainwater Harvesting	Reduce CO_2 Emissions	A sustainable method of reusing rainwater for grey water usage in households and for irrigation of landscapes	CO_2 saving of 50% (James et al., 2018)
Active Transport	Reduce CO_2 Emissions	A sustainable method of travel, which involves walking, cycling and other non-motorised modes	CO_2 saving of 17% (Brand et al., 2014)

Table 1. A summary of the measures outlined in the literature review, including their function, a brief description and quantification.

CASE STUDIES REVIEW

INTRODUCTION

In the UK, the average person is responsible for around 10 tCO_2-equivalents each year (World Bank, 2019), which begs the question - do low-carbon neighbourhoods have the potential to significantly reduce this figure? In order to answer this question, a number of case studies have been selected that represent good examples of best practice in low-carbon neighbourhood design. In particular, each case study comprises measures that both enhance carbon storage and reduce CO_2 emissions. The first two case studies - BedZED, South London and Upton, Northampton - are located in the UK, which makes them suitable for this project as the design tool-kit will be tested on a site located in the UK. The third and final case study - Kronsberg, Hanover - is located in Germany, which is beneficial as it provides an insight into a different national context. Notably, each case study is a different size, which allows the impact of scale to be assessed.

BedZED, South London

Upton, Northampton

Kronsberg, Hanover

CASE STUDY: BEDZED, SOUTH LONDON

DEVELOPERS	TIMELINE	DWELLING UNITS	COMMERCIAL AREA	LAND AREA	CO_2 EMISSIONS
BioRegional Development Group & Peabody Trust	1996-2002	82	2,500 m^2	1.6 hectares	7.7 tCO_2 per person per year

BACKGROUND

The Beddington Zero Energy Development (BedZED) is a sustainable development in Wallington, South London. The development was built with the goal of achieving net zero carbon emissions through the use of alternative energies, including 777 m^2 of PV panels and a biomass Combined Heat and Power (CHP) plant (Bioregional, 2016). In order to reduce energy use, windows are triple glazed, buildings are insulated and airtight, and passive solar heating is maximised through building orientation and south facing sunspaces (Bioregional, 2016). Moreover, wind cowls provide natural ventilation (Bioregional, 2016). In regard to transport, the development has a unique car-share programme that uses solar panels to power around 40 electric cars (Farr, 2008). In addition to this, bicycle storage is provided to encourage active transport. Although the development is high density, it provides ample private and shared green space, including green roofs (Bioregional, 2016). In order to prevent flooding on the site, stormwater drainage is directed into vegetated bioswales (Farr, 2008). Notably, sustainability was also considered during construction, as 52% of construction materials were sourced within 56 km of the site and 15% were reused or recycled (Bioregional, 2016). As a result of the aforementioned measures, the development reduced gas consumpton by 36%, electricity consumpton by 27%, and fossil fuel consumption from travel by 53% (Bioregional, 2016). Overall, the total carbon footprint associated with the development has been reduced by 23% (Bioregional, 2016).

Figure 12. BedZED, South London (Zed Factory, 2009)

Figure 13. Green roof (Zed Factory, 2009)

Figure 14. Wind cowls (Zed Factory, 2009)

Figure 15. Open space (Zed Factory, 2009)

Figure 16. Sunspaces (Zed Factory, 2009)

LESSONS LEARNED

It is fair to say that BedZED is a good example of best practice, as the development has significantly reduced CO_2 emissions per person via good building design (Chance, 2009). Furthermore, the development has reduced CO_2 emissions through the encouragement of sustainable behaviour, such as reduced water use and car sharing (Chance, 2009). The success of BedZED can be attributed to its multifaceted approach to sustainable development. In particular, the development aims to reduce CO_2 emissions from both the construction and occupation phases of a building's life-cycle, as well as through transport, food and waste (Chance, 2009). Today, the developers claim that BedZED is "the most ambitious attempt at all-round sustainability in a major new housing development" (Bioregional, 2016).

Although the success of BedZED is clear, the development has experienced a number of problems since its construction. To begin with, the original woodchip-burning CHP plant required constant maintenance, and as a result, it has been replaced by a biomass boiler that burns wood pellets (Bioregional, 2016). In addition to this, rainwater harvesting has been halted due to concerns about contaminated from the manure used on the green roofs, and the on-site water treatment plant was closed due to its high electricity consumption (Bioregional, 2016). Notably, the development is limited by its location, as residents can only get to certain destinations via public transport. Evidently, the success of a development is impacted by the local context, which stresses the importance of considering context when designing low-carbon neighbourhoods.

CASE STUDY: BEDZED, SOUTH LONDON

1. Biomass CHP Plant
2. Sports Court
3. Healthy Living Centre
4. Central Square
5. Organic Cafe & Shop
6. Vegetated Bioswale

Figure 17. Map of BedZED, South London

CASE STUDY: UPTON, NORTHAMPTON

DEVELOPERS	TIMELINE	DWELLING UNITS	COMMERCIAL AREA	LAND AREA	CO_2 EMISSIONS
English Partnerships	2002-2011	1,400	700 m^2	42.9 hectares	8 tCO_2 per person per year

BACKGROUND

Upton, a town located to the south-west of Northampton, is a sustainable urban extension that showcases best practice in design and development (ADS, 2011). The development is divided into eight sites, each of which demonstrates a range of different sustainable technologies. A few examples of the technologies used are: PV panels, micro CHP, rainwater harvesting, extensive green roofs, solar water heating, and mini wind turbines (Farr, 2008). In order to create a neighbourhood based on sustainable urbanism, the 'Enquiry by Design' process was used to select design requirements (Crew, 2013). The design requirements were used to create the 'Upton Code', which ensures that the development has a walkable urban form, a good public transport network, ample open space, and numerous local facilities (Crew, 2013). All homes in the development had to achieve the BREEAM EcoHomes rating of 'Excellent', and CO_2 emissions were capped at 0.025 t/m^2/yr to achieve this standard (Farr, 2008). In addition to this, all developers had to secure green energy tariffs (Farr, 2008). In regard to transport, a scenic cycle route along the River Nene, which spans 2.5 miles, connects Upton to Northampton (Transport for New Homes, 2018). A characteristic aspect of the development is the extensive SUDS network, which controls the flow and quality of water entering the sewer system (Farr, 2008). For example, surface run-off is directed into vegetated bioswales, and porous paving allows rainwater to penetrate the surface of roads, pavements and courtyards (Farr, 2008).

Figure 18. Upton, Northampton (The Land Trust, 2015)

Figure 19. Green roof with mini wind turbines (Arup, 2010)

Figure 20. Bioretention basin (The Land Trust, 2015)

Figure 21. Vegetated bioswale (The Land Trust, 2015)

Figure 22. Sustainable housing with PV panels (Arup, 2010)

LESSONS LEARNED

Upton is a good example of best practice, as it uses a range of design measures to tackle multiple issues related to climate change. Specifically, the development has a strong focus on the use of SUDS to manage stormwater. Importantly, the development is designed to encourage active transport, as the streets are navigable and partly car-free (Transport for New Homes, 2018). In addition to this, there is a regular bus service from Upton to Northampton, which discourages the use of the private car (Transport for New Homes, 2018). The use of the Enquiry by Design process to create the Upton Code was crucial to the success of the development, as it ensures that sustainability was considered across the site. Moreover, it ensured that the stakeholders involved in the project were aware of the requirements of the development, and that the community was engaged.

The ability of SUDS to store carbon has not been explicitly mentioned, which represents a missed opportunity for the development. As a result, the type and variety of vegetation planted in the SUDS network might not be optimal for carbon storage. The open space inside of residential blocks is primarily used for parking space, which suggests that the extent of the SUDS network could be improved (Transport for New Homes, 2018). Another issue with the development is the existing transport network, which encourages travel by private car as two major roads sever the site from the surrounding urban area (Transport for New Homes, 2018). In addition to this, the high street has a lack of facilities, which further encourages travel by private car (Transport for New Homes, 2018). Ultimately, this stresses the importance of considering sustainability at the neighbourhood scale.

CASE STUDY: UPTON, NORTHAMPTON

1. Supermarket
2. Bioretention Basin
3. Primary School
4. Central Square
5. Woodland
6. Vegetated Bioswale

Figure 23. Map of Upton, Northampton

CASE STUDY: KRONSBERG, HANOVER

DEVELOPERS	TIMELINE	DWELLING UNITS	COMMERCIAL AREA	LAND AREA	CO_2 EMISSIONS
City of Kronsberg	1990-present	5,000	35,024 m^2	159.9 acres	2.6 tCO_2 per person per year

BACKGROUND

Kronsberg, located in a district to the south-east of Hanover, is a sustainable development known for its ambitious energy reduction goals, transit-oriented design and mixed-income residential areas (Farr, 2008). It is quite a unique case, as the development was constructed for the EXPO 2000, which was held in Hanover. The use of solar panels, wind turbines, passive house, and a co-generation heating network have all enabled energy reduction goals to be met (Farr, 2008). In particular, the requirement for residents to connect to a district heating network caused a 23% reduction in CO_2 emissions alone (Farr, 2008). In addition to this, a set of principles, called the Kronsberg Standard, have ensured that green building guidelines are built into land contracts (Farr, 2008). The majority of the buildings are two to four storeys high, as the development was built with high density in mind (Heimkehr, 2017). In order to reduce emissions from transport, the development was designed so that all residents are within 1/3 mile of an underground station (Farr, 2008). In addition to this, there are only 0.8 parking spaces per household, which discourages private car use (Farr, 2008). A designated bicycle street runs through the development, and the grouping of mixed-use buildings creates a pedestrian-friendly environment for residents (Farr, 2008). The development has over 1,000 street trees and two large parks, which have the potential to store a large amount of carbon (Heimkehr, 2017). By 2001, the development experienced a 74% reduction in CO_2 emissions, compared with conventional developments (Farr, 2008).

Figure 24. Kronsberg, Hanover (Pizza Travel, 2014)

Figure 25. Boulevard (Pizza Travel, 2014)

Figure 26. Green roof with PV panels (Pizza Travel, 2014)

Figure 27. Housing with PV panels (Pizza Travel, 2014)

Figure 28. Large park (Pizza Travel, 2014)

LESSONS LEARNED

Kronsberg is a good example of best practice, as it illustrates how a large development can be designed in a sustainable manner. A particularly successful feature of this project is the district heating network, as it significantly reduced the CO_2 emissions associated with the development. Another strong aspect of the development is the underground service that links the development with the city centre, as well as the bicycle street, which encourages active transport. However, it must be noted that the success of this project is largely down to the strong influence of the City of Kronsberg, who were able to monitor the development from planning to construction (Rumming, n.d). The developers were able to implement the Kronsberg Standard due to this influence, which ensured that buildings were built to a high standard with regards to sustainability.

There is a fundamental issue with Kronsberg - it was built on a large span of arable land (Heimkehr, 2017). A significant amount of carbon is stored in the soil of arable land, which would have been released into the atmosphere when the soil was disturbed during the construction of the development. Hence, it is always preferable that new developments are built on brownfield sites or greenfield sites that have poor soil conditions, and therefore a low carbon storage potential.

COMPARISON OF CASE STUDIES

IMPACT OF SCALE

As can be seen, the smallest development is BedZED, followed by Upton, and the largest is Kronsberg. Notably, these case studies have some similarities, but also many differences, which can be attributed to scale. For example, BedZED has a large commercial square footage relative to its land area, because the buildings are designed as living and working units. In doing so, residents do not need to travel out of the development for work. In comparison, Upton has a relatively small commercial square footage relative to its land area, which suggests that residents are more car dependent. Conversely, good public transport links, combined with a significant commercial square footage, allows residents in Kronsberg to both travel to work via public transport and work from home. Ultimately, it is vital that the neighbourhood scale is considered during the planning of low-carbon neighbourhoods as this scale greatly influences sustainable behaviours.

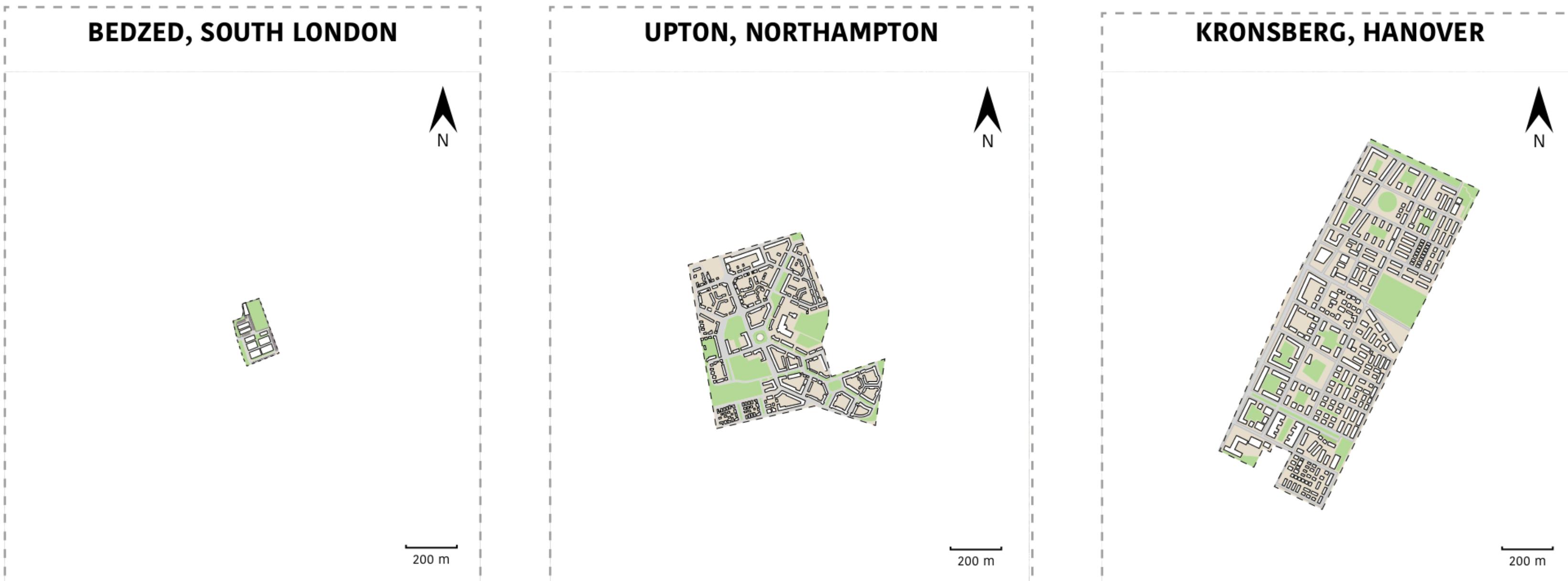

Figure 30. A comparison of the scale of the three case studies.

COMPARISON OF CASE STUDIES

KEY

● PRESENT ○ NOT PRESENT

MEASURE	BEDZED, SOUTH LONDON	UPTON, NORTHAMPTON	KRONSBERG, HANOVER
Green Infrastructure	●	●	●
Trees and Vegetation	●	●	●
Sustainable Materials	●	○	○
SUDS	●	●	●
Insulation	●	●	●
Triple Glazing	●	●	●
Renewable Energy	●	●	●
Rainwater Harvesting	○	●	○
Active Transport	○	●	●

Table 2. A comparison of the measures implemented in the three case studies.

DESIGN TOOL-KIT

INTRODUCTION

A design tool-kit has been created by drawing from the literature review and selecting the best measures used in the case studies. The tool-kit comprises three main aspects: physical infrastructure, the environmental aspect, and the social aspect. In doing so, climate change can be tackled while simultaneously improving the local community. Notably, sustainable development encompasses three dimensions - environmental, social and economic - that must all be addressed when designing new neighbourhoods.

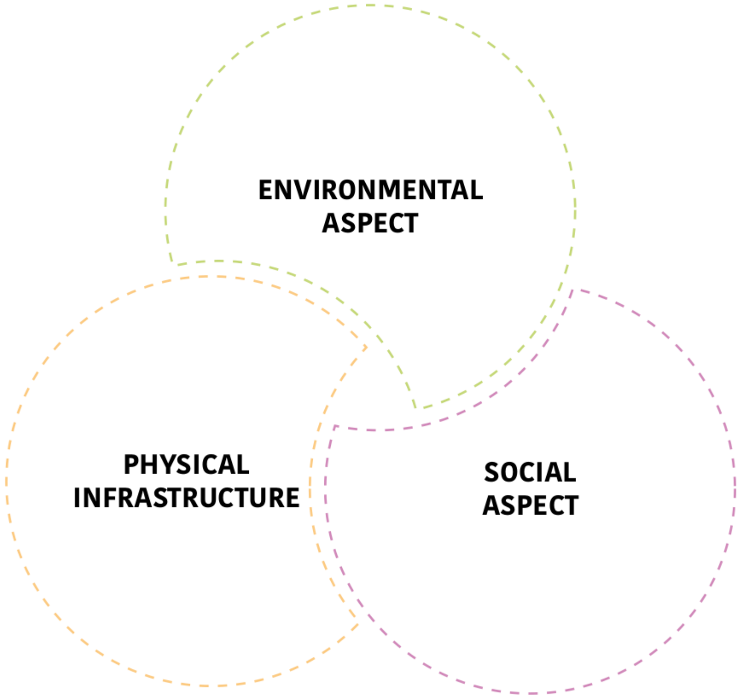

Figure 32. The three aspects of the design tool-kit.

DESIGN TOOL-KIT

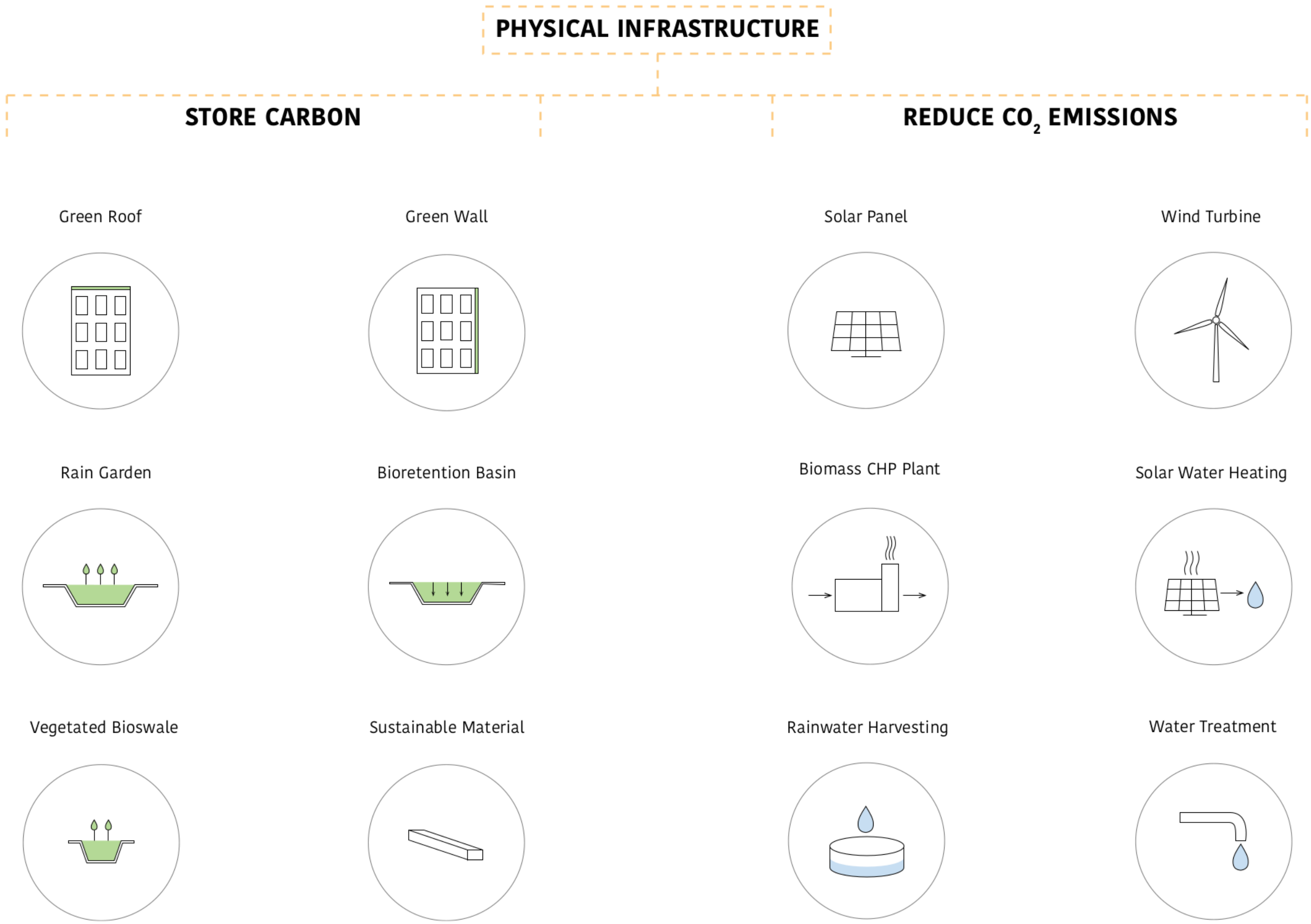

Figure 33. Components of the physical infrastructure aspect of the design tool-kit.

DESIGN TOOL-KIT

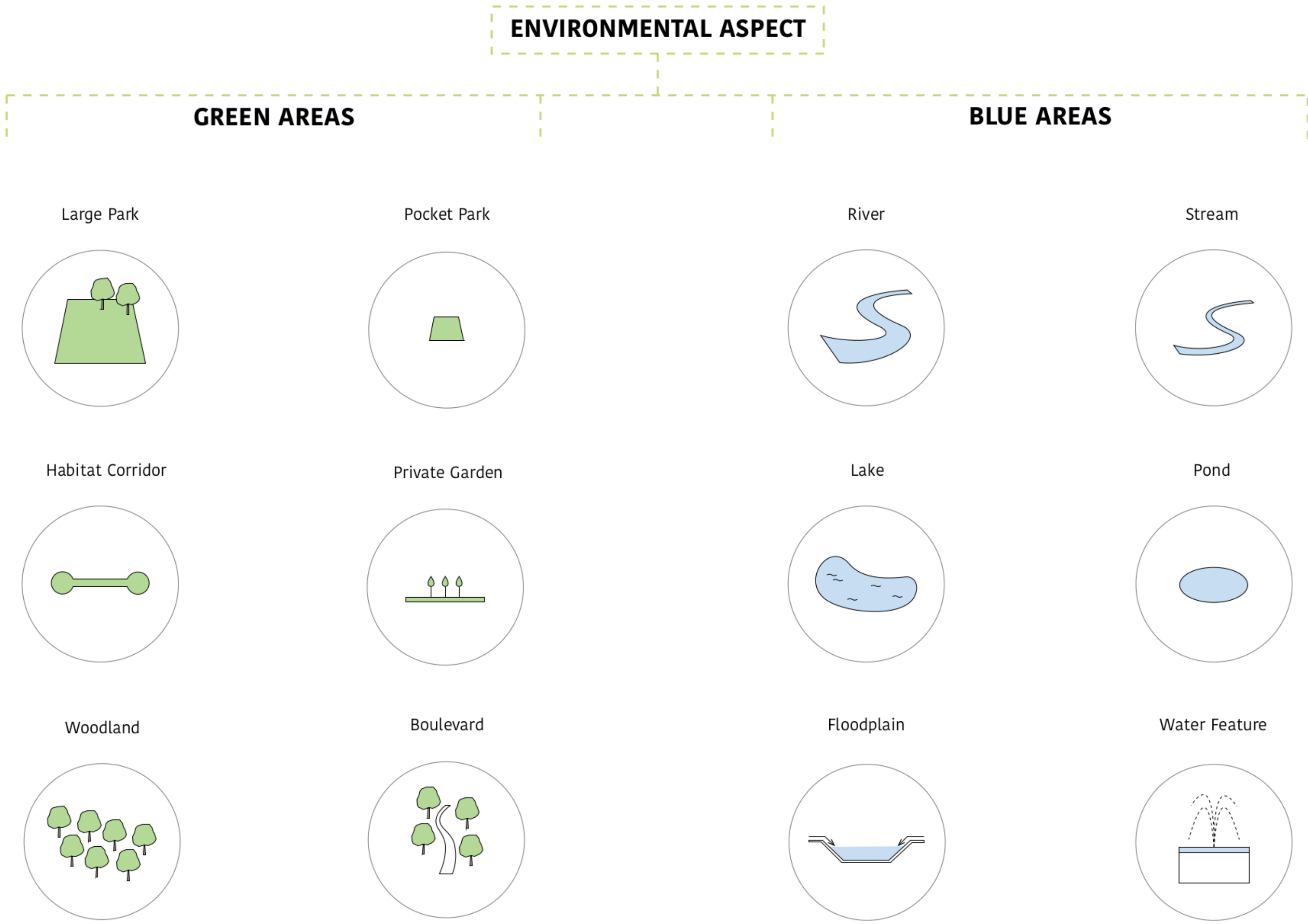

Figure 34. Components of the environmental aspect of the design tool-kit.

DESIGN TOOL-KIT

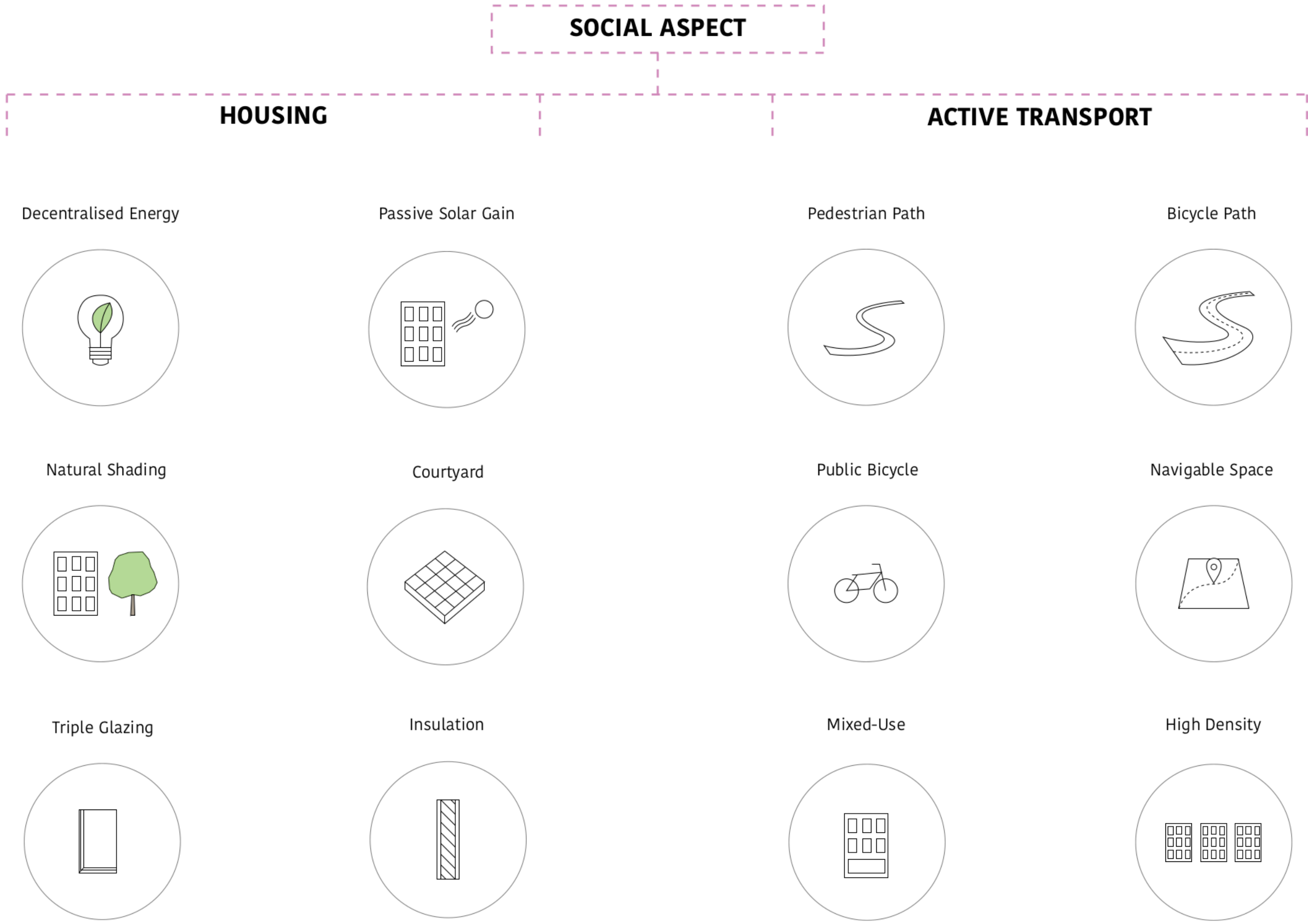

Figure 35. Components of the social aspect of the design tool-kit.

DESIGN TOOL-KIT

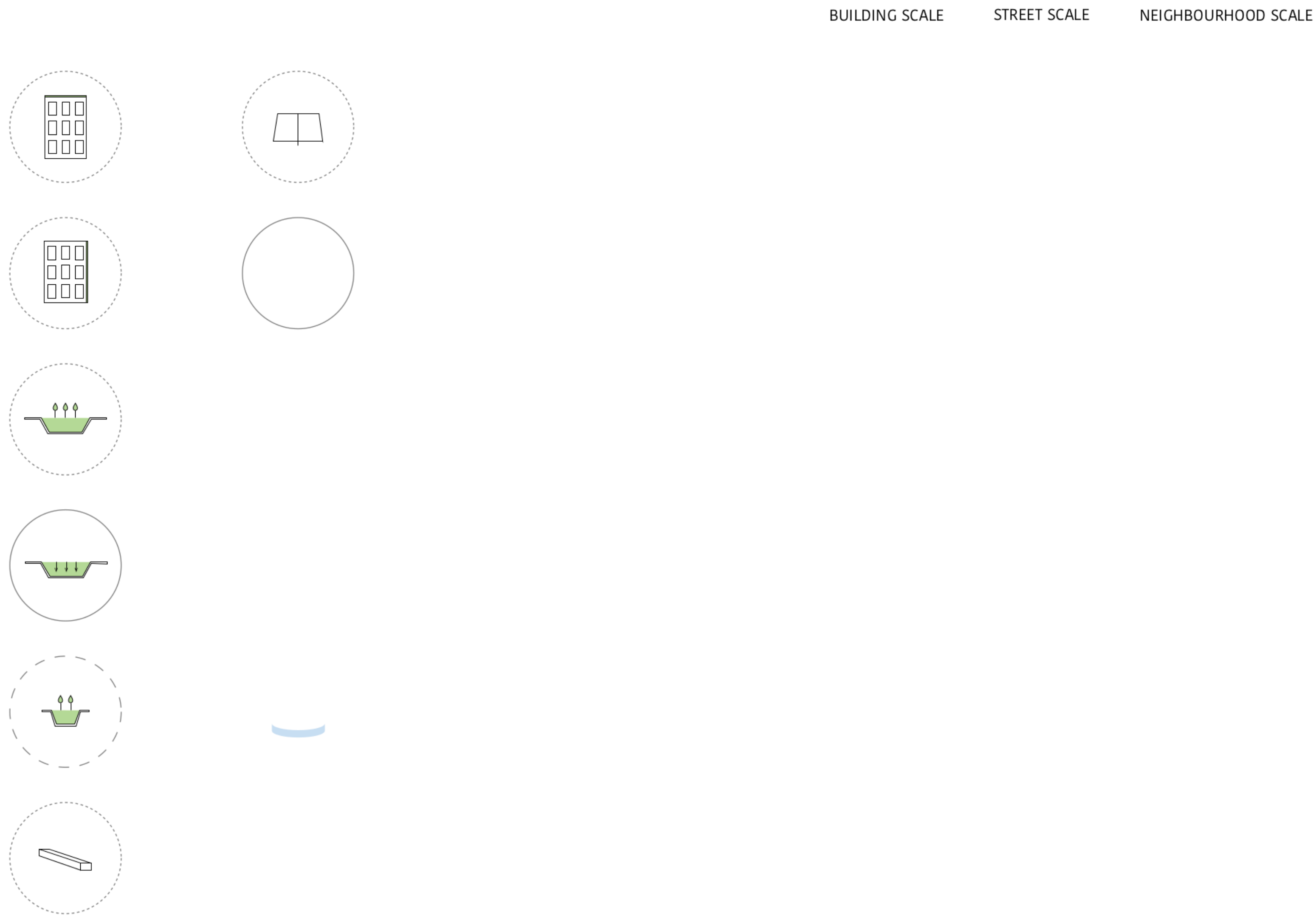

Figure 36. Scale of implementation of each component of the design tool-kit.

DESIGN TOOL-KIT

PLANT SPECIES

It is important to consider plant species, as this will ensure that the biotic components of the design tool-kit are effective. For example, the plant species on green roofs and walls need to survive various weather conditions and should also be low-maintenance. Moreover, the plant species in SUDS need to be able to tolerate both dry and wet conditions. Finally, tree species need to be efficient at storing carbon, provide shade and withstand flooding.

Figure 37. Components of the design tool-kit that need specified plant species.

DESIGN TOOL-KIT

Figure 38. Examples of plant species suitable for green roofs and walls (RHS, 2009)

DESIGN TOOL-KIT

Figure 39. Examples of plant species suitable for SUDS (RHS, 2017)

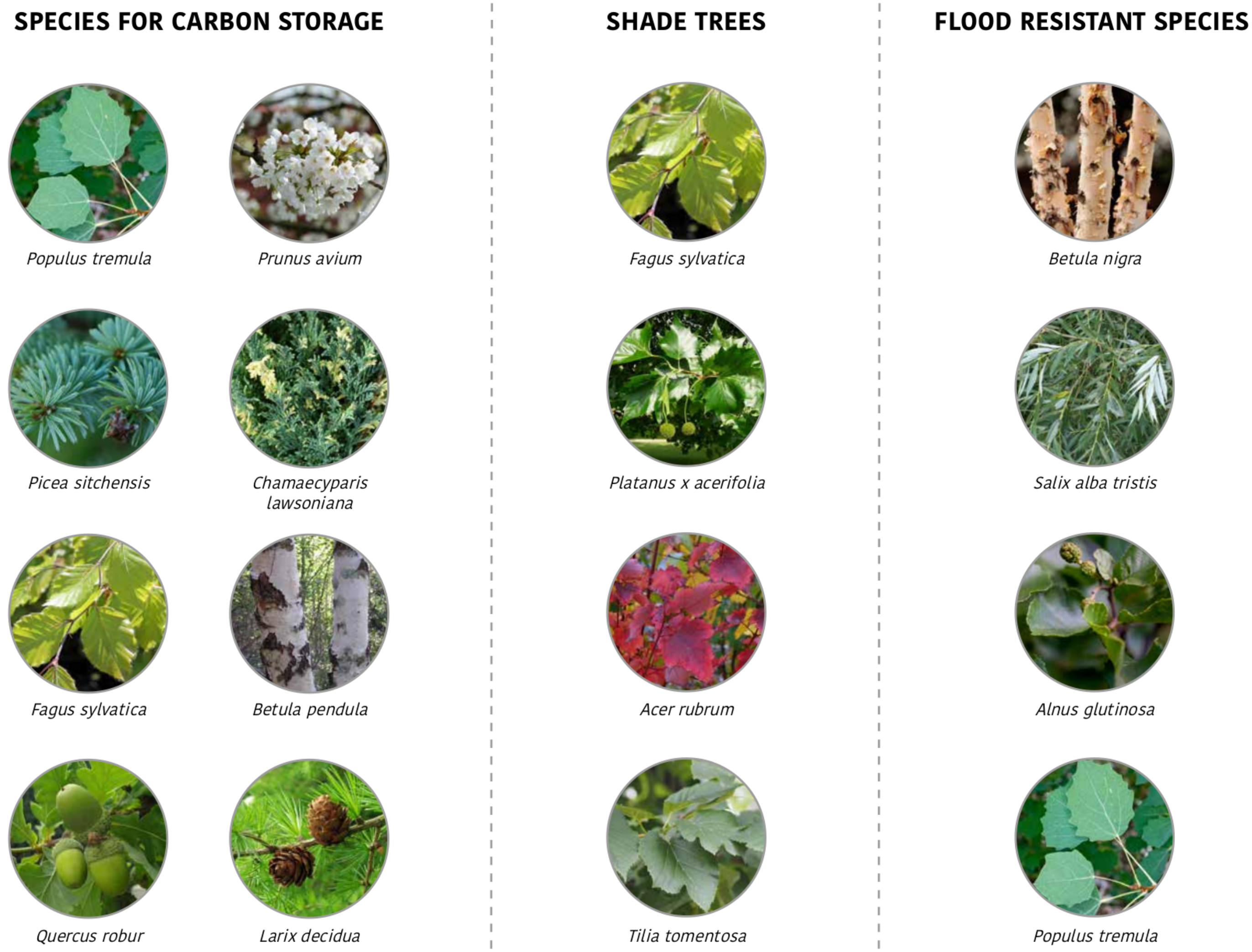

Figure 40. Examples of suitable tree species (Cannell, 1999; Barcham, 2014; Hewitt et al., n.d)

DESIGN OBJECTIVES

4. To outline design proposals that can be used to increase carbon storage and reduce CO_2 emissions at various scales in a specific urban area

1. Provide an overview of the site, including justification of the site, and analyse the site in order to identify its strengths and weaknesses

2. Establish a set of design proposals at the building, street and neighbourhood scale

3. Outline a number of specific interventions that will be particularly beneficial to enhancing carbon storage and reducing CO_2 emissions

4. Highlight any limitations of the design proposals and conclude with the carbon-saving potential of the site

APPLICATION

In this section, an overview of the site will be provided, including a brief background of the site and justification of the site choice. Following this, the site will be analysed in detail to determine its strengths and weaknesses, as well as any opportunities and threats. Next, a range of design proposals at the building, street and neighbourhood scale will be presented, drawing from the design tool-kit. Finally, a summary of interventions will be illustrated on the site map.

SITE OVERVIEW

DEVELOPERS	TIMELINE	DWELLING UNITS	COMMERCIAL AREA	LAND AREA	CO_2 EMISSIONS
English Partnerships	1999-present	1,746	4,462 m^2	25.8 hectares	no figure calculated

BACKGROUND & JUSTIFICATION

Greenwich Millennium Village (GMV) is a sustainable development located on the Greenwich Peninsula in Greenwich, South East London. The government conceived it as an experimental project, with a focus on reducing CO_2 emissions, as well as energy and water sustainability, access to public transport, habitat recreation, and building innovation (Kim and Lee, 2013). This project is unique as a range of sustainability targets, indicators and benchmarks were established in order to access the success of the project in terms of sustainability (Kim, 2005).

The site was derelict and contaminated prior to the commencement of the project, and development only became feasible once the government decided to run the Jubilee Line through the peninsula, with a station near the Millennium Dome - now the O^2 Arena (TEN, 2009). The developers of the project are Countryside Properties and Taylor Wimpey, who were selected through a competition, and the masterplan was created by Ralph Erskine (Kim, 2005). However, English Partnerships is the landowner and therefore has control over the project (Kim, 2005).

A primary goal of the development is to reduce primary energy consumption by 80%, but the development also seeks to reduce the embodied energy associated with buildings by 50% and water consumption by 30% (Hodkinson, 2000). Hence, GMV is a suitable site to test out the design tool-kit as it is already striving to be a low-carbon neighbourhood. The design tool-kit can show what more can be done, via sustainable urban design, to meet the targets set out by the project.

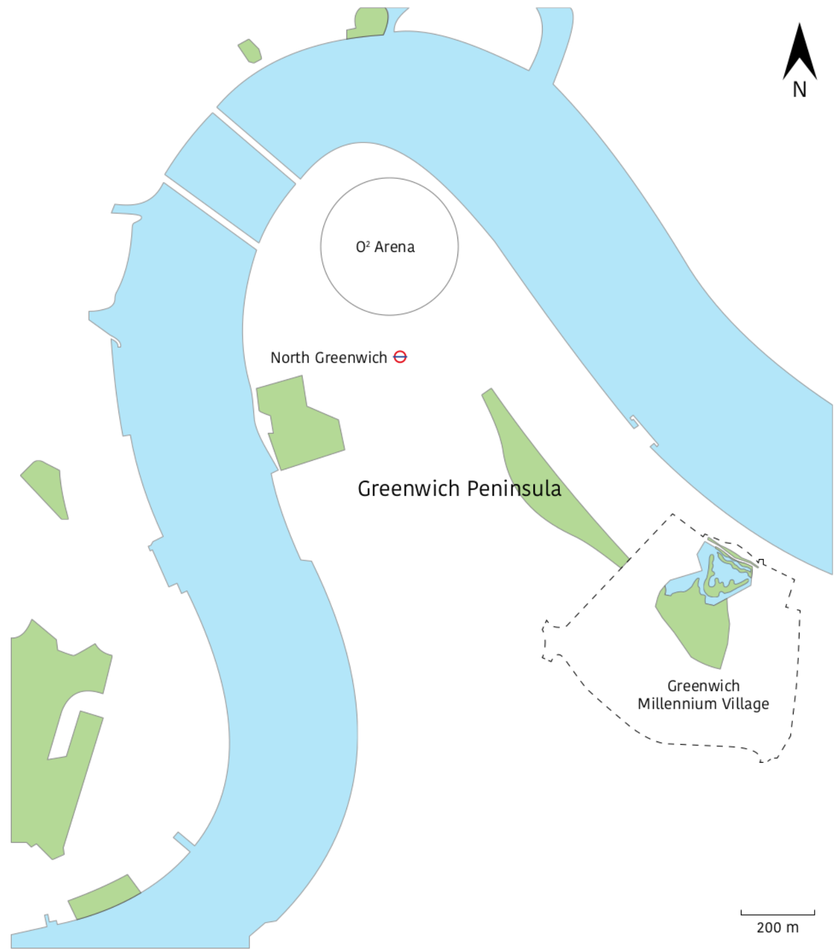

Figure 41. Location of Greenwich Millennium Village on the Greenwich Peninsula.

SITE OVERVIEW

POTENTIAL OF SITE

GMV is situated in a unique location, bounded on three sides by the meander of the River Thames, which makes it vulnerable to flooding. The site features a four-acre freshwater wetland, which includes two lakes, as well as areas of beach, marsh, meadow and wet woodland (Ecology Park). In addition to providing a natural flood defence, this area acts as a unique habitat.

A park sits in the middle of the site, covering the area of 20 football pitches (Southern Park). A total of 60,000 shrubs and 12,000 trees have been planted in the park, but carbon storage is not mentioned in any plans. It may seem like the development has sufficient green space, but residents have complained about the lack of greenery (TEN, 2009). This suggests that the site needs a more extensive green network.

GMV has the potential to store a significant amount of aboveground carbon, as well as belowground carbon, due to the soil type present on the site. Specifically, the land surrounding the River Thames consists of a loamy and clayed soil, which has the capacity to store a significant amount of carbon compared to other soil types in the surrounding area.

Figure 42. Current masterplan of Greenwich Millennium Village.

SITE ANALYSIS

WEAKNESSES OF CURRENT HOUSING STOCK

The majority of the buildings at GMV, including Holly Court (Figure 43), are constructed with concrete frames, which is not a sustainable material. In order to reduce CO_2 emissions and store carbon in the structure of the building, CLT should be used as the primary building material. In addition to this, Holly Court features a steel barrel vault-roof, as opposed to a green roof, which could store carbon and provide a broad range of ecosystem services. On the ground floor of Holly Court, there is an indoor car park, which encourages car use. Again, this is an unsustainable aspect of the development as it encourages private car use. Instead, the building should provide bicycle storage so that residents use active transport.

Figure 43. Holly Court, GMV (Ramboll, n.d)

WEAKNESSES OF GREEN NETWORK

The existing green network does not integrate into the development well, as hard barriers exist between green areas and physical infrastructure (Figure 44). In particular, the site does not make use of more natural stormwater management techniques, such as SUDS. To add to this, green and blue areas are concentrated to the north of the site, which means that ecosystem services are not distributed evenly across the development for residents.

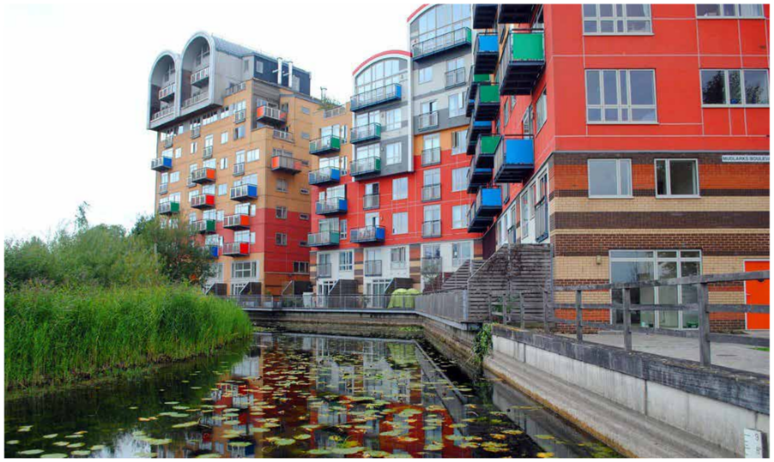

Figure 44. Swan Lake, GMV (Flickr, 2018)

SITE ANALYSIS

KEY

PRESENT ● NOT PRESENT ○

COMPONENT	BEDZED, SOUTH LONDON			UPTON, NORTHAMPTON			KRONSBERG, HANOVER			GMV, EAST LONDON		
	●	○	○	●	○	●	●	●	●	○	○	○
	○	●	●	●	●	○	○	●	○	○	○	○
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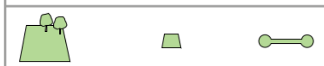	○	○	○	●	●	○	●	●	○	●	○	○
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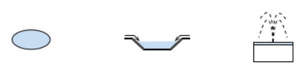	○	●	○	●	●	●	○	●	○	○	●	○
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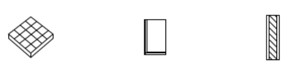	●	●	●	●	●	●	●	●	●	○	○	○
	●	○	○	●	●	○	●	●	●	●	●	○
	○	○	●	○	○	●	●	●	●	○	●	●

Table 4. A comparison of the components present in the case studies with those present at GMV.

SITE ANALYSIS

STRENGTHS

The Ecology Park and Southern Park contribute to biotic carbon storage, and the Energy Centre helps to reduce CO_2 emissions associated with energy. In addition to this, rainwater harvesting helps to reduce the CO_2 emissions associated with water use. Finally, the development has pedestrian and bicycle paths, and is mixed-use and high density.

WEAKNESSES

The site does not incorporate any green roofs or walls, and there is no SUDS network. Energy is not generated from solar panels or wind turbines, and there is no on-site water treatment. Plus, there are no pocket parks, habitat corridors or boulevards. Buildings do not benefit from natural shading and the development is not car-free.

OPPORTUNITIES

The future residential development can be redesigned to maximise carbon storage and reduce CO_2 emissions. Moreover, there is potential to implement a number of interventions, including a bioretention basin, vegetated bioswales and new park. Finally, there is potential to improve the energy centre and add solar panels to buildings.

THREATS

As the site is situated in a prime location, the ability of the development to achieve a significant reduction in CO_2 emissions could be compromised due to the desire of developers to cut corners in order to maximise profit. In addition to this, there is a significant threat of flooding, and existing stormwater management is poor.

Figure 45. SWOT map of Greenwich Millennium Village.

BUILDING SCALE

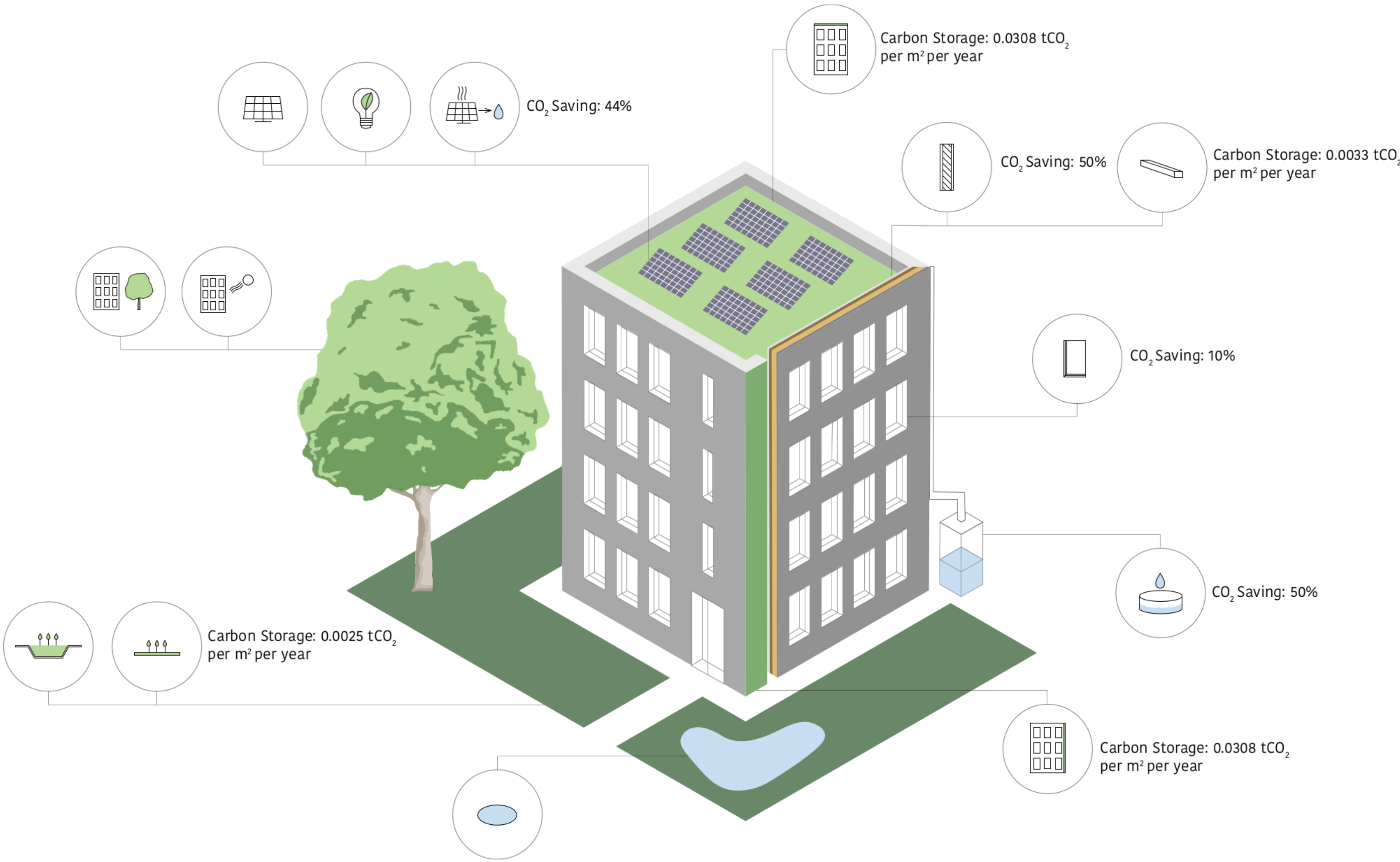

Figure 46. Application of the design-tool kit at the building scale.

BUILDING SCALE

STRUCTURE OF BUILDING

CLT will be used to construct the frames of new buildings, thus enhancing carbon storage. Insulation will be used in both new and existing buildings to reduce energy consumption, and therefore reduce CO_2 emissions.

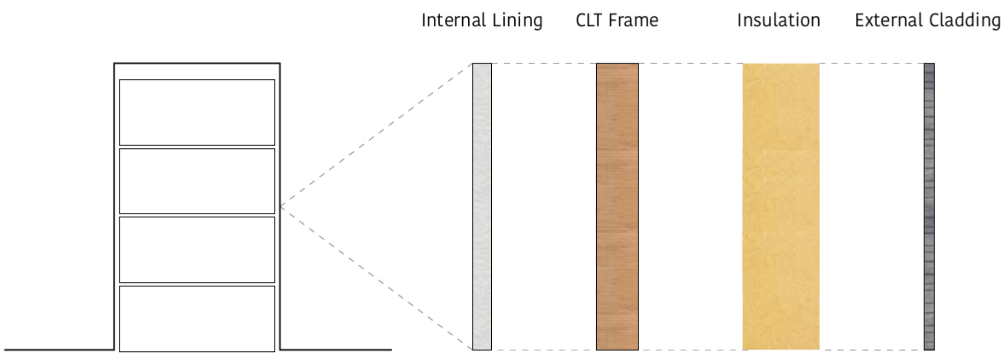

Figure 47. A cross-section of the structure of a building.

TREES AS TEMPERATURE MODERATORS

In summer, deciduous trees provide natural cooling to buildings through the provision of shade. Consequently, residents will not have to use air conditioning. In winter, deciduous trees allow the natural heating of buildings as the sun is lower in the sky, and solar energy can pass through the tree due to the absence of leaves. Hence, energy use is reduced, thus reducing CO_2 emissions.

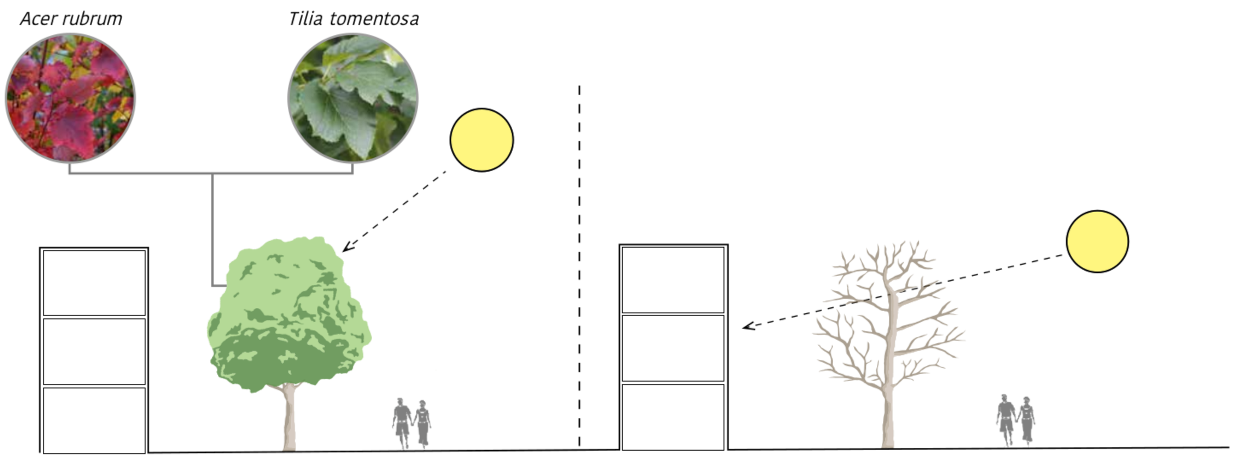

Figure 48. A cross-section showing a tree providing shade to a building in summer (left) and allowing the sun to penetrate the building in winter (right)

SKY PROMENADE

The “Sky Promenade” will be a multi-functional space, acting as both a green roof and a sunspace. In doing so, carbon storage can be enhanced, and residents will have somewhere warm to go to during winter. There is potential to grow food in this space, which will further reduce the CO_2 emissions associated with the site. Rainwater harvesting can be utilised to irrigate the plants.

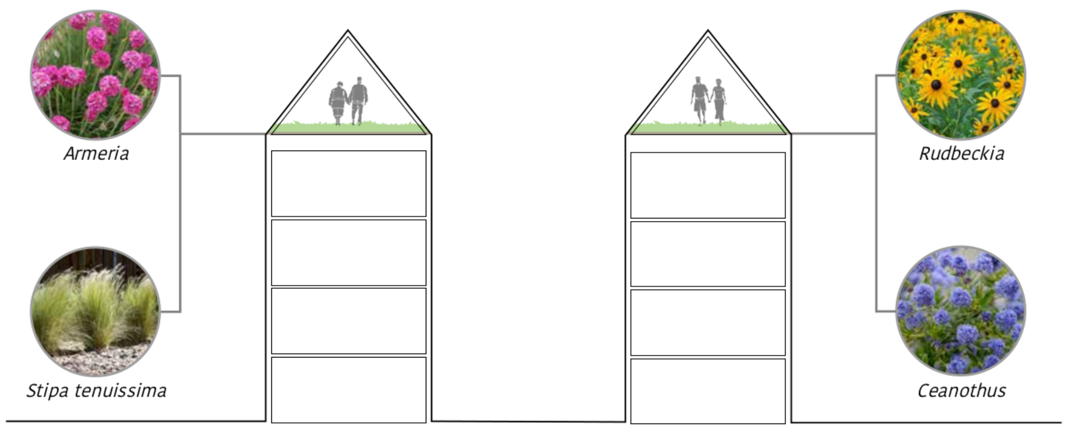

Figure 49. A cross-section of the Sky Promenade.

STREET SCALE

Figure 50. Application of the design-tool kit at the street scale.

STREET SCALE

COMPOSITION OF THE STREET

The buildings that line the street will be mixed-use, with commercial stores on the ground floor and residential flats on the upper floors. The green roof will provide a private garden for residents.

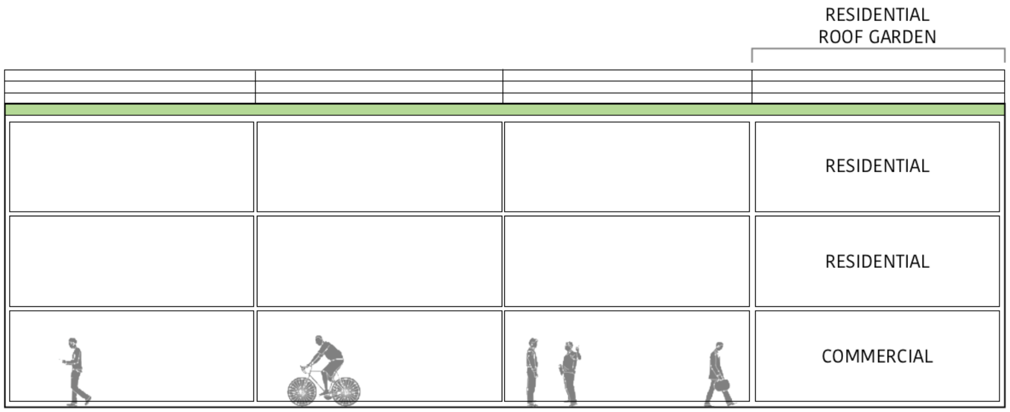

Figure 51. A cross-section of the street scale.

ACTIVE BOULEVARD

The “Active Boulevard” will run through the middle of the development from east to west, connecting the site to the surrounding area through the provision of infrastructure for active transport. In particular, a bicycle path and a pedestrian path in the form of a boulevard will connect GMV to key nodes such as North Greenwich underground station. A habitat corridor and vegetated bioswale will run along the boulevard to enhance biotic carbon storage, but also to provide ecosystem services, such as the regulation of water flows.

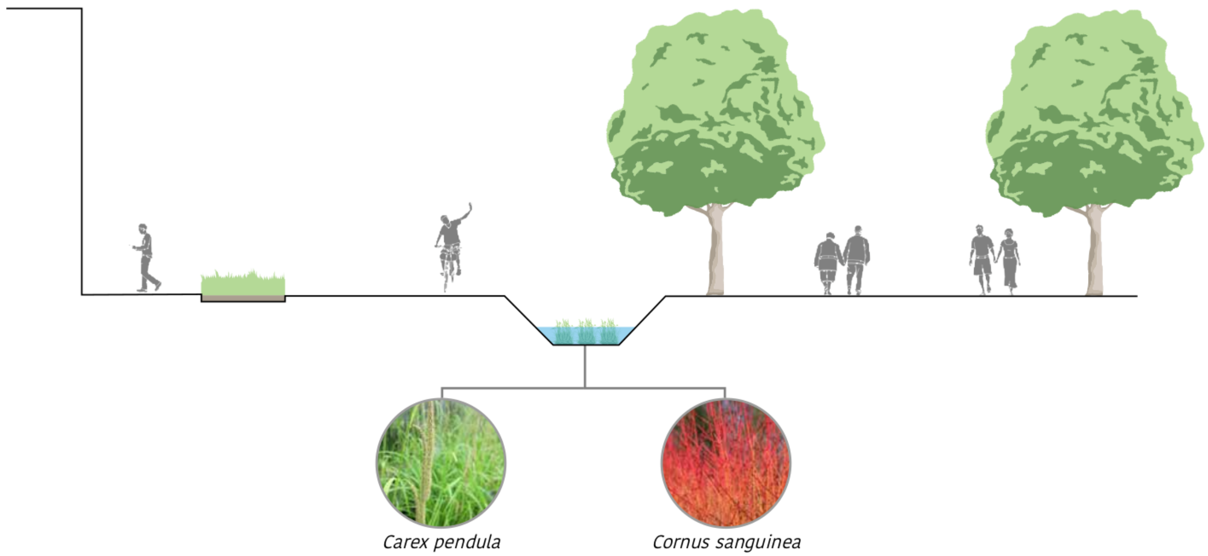

Figure 52. A cross-section of the Active Boulevard.

ANIMATED COURTYARD

The “Animated Courtyard” will be an area for residents to gather and interact, with a central water feature that has tiered edges that act as seats. Two small water channels will run along the courtyard to direct stormwater towards the River Thames, since urban areas tend to redirect natural streams.

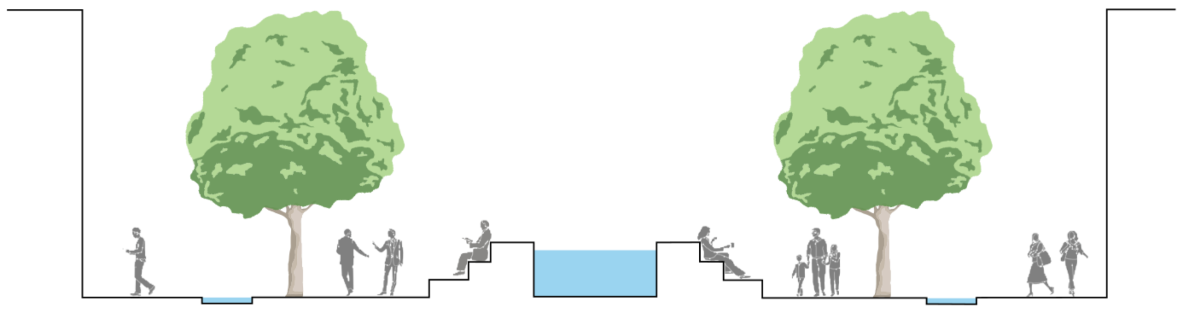

Figure 53. A cross-section of the Animated Courtyard.

NEIGHBOURHOOD SCALE

Figure 54. Application of the design-tool kit at the neighbourhood scale (exact location shown in site map on top right corner).

SUNKEN SQUARE

The “Sunken Square” is a bioretention basin that will be located in the new neighbourhood. This feature will be designed as a flexible space, as recreational activities will vary depending on the level of water within the basin. A variety of suitable plant species will be planted in the basin, and suitable tree species will be planted in the area surrounding the basin, to optimise carbon storage. The trees will also provide shade and wind protection for residents visiting the area.

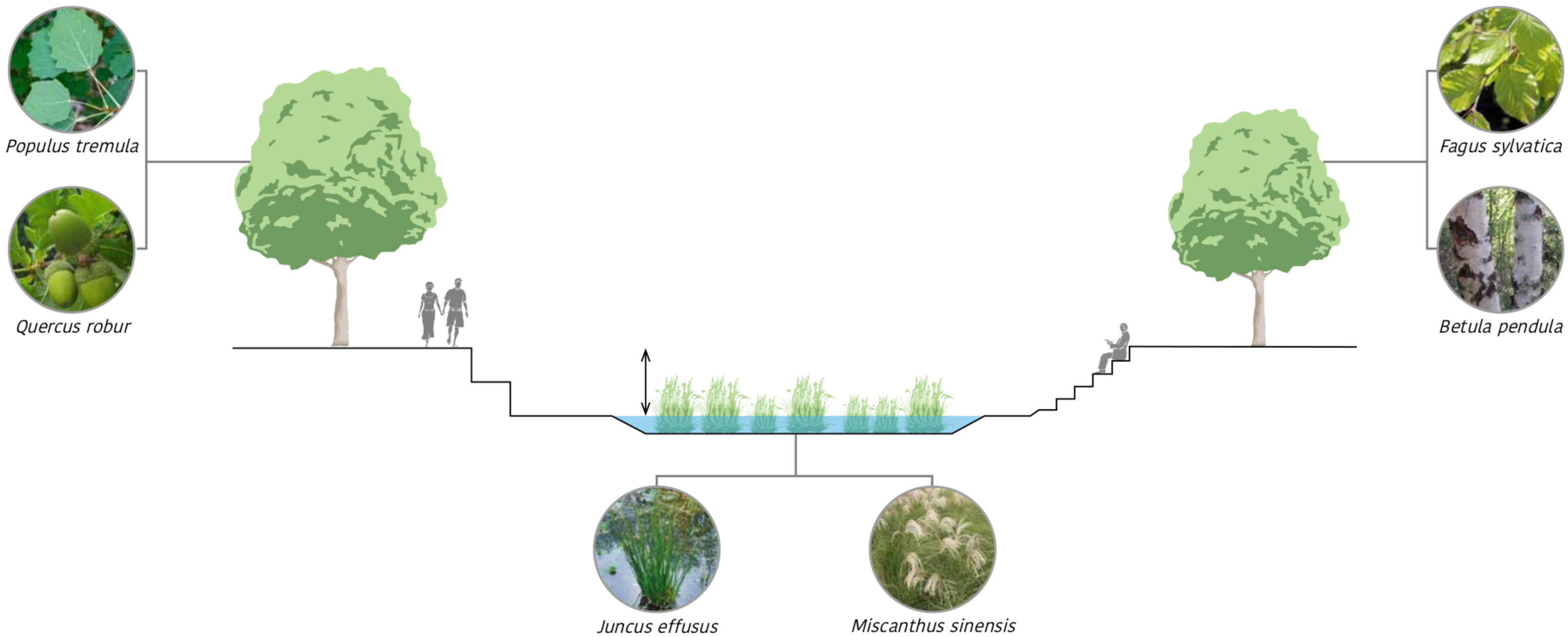

Figure 55. A cross-section of the Sunken Square.

NEIGHBOURHOOD SCALE

ACTIVE TRANSPORT NETWORK

An improved network of walking and cycling infrastructure will be implemented across the entire site, in order to encourage active transport among residents. The development will also be transformed into a car free zone, and only residents with special requirements will be allowed a permit for car use.

Figure 56. Proposed network of active transport infrastructure at GMV.

NEIGHBOURHOOD SCALE

GREEN NETWORK

At present, green areas are not evenly distributed across the site, which reduces the ability of the development to store carbon. The proposed green network includes a new large park located on the site of the former residents' car park, as well as numerous pocket parks and an extensive network of SUDS.

Figure 57. Proposed green network at GMV.

SUMMARY OF INTERVENTIONS

TOTAL AREA OF SITE: 258,000 m²

TOTAL CO_2 EMISSIONS: 41,904 tCO_2 per year based on 10 tCO_2 per person per year, 1,746 dwellings, and the UK average of 2.4 people per dwelling

TOTAL CARBON STORAGE: 4,203 tCO_2 per year
TOTAL CO_2 SAVINGS: 8,465 tCO_2 per year (20.2%)

NEW TOTAL CO_2 EMISSIONS: 29,236 tCO_2 per year or 7 tCO_2 per person per year, which equates to a 30.2% reduction in CO_2 emissions

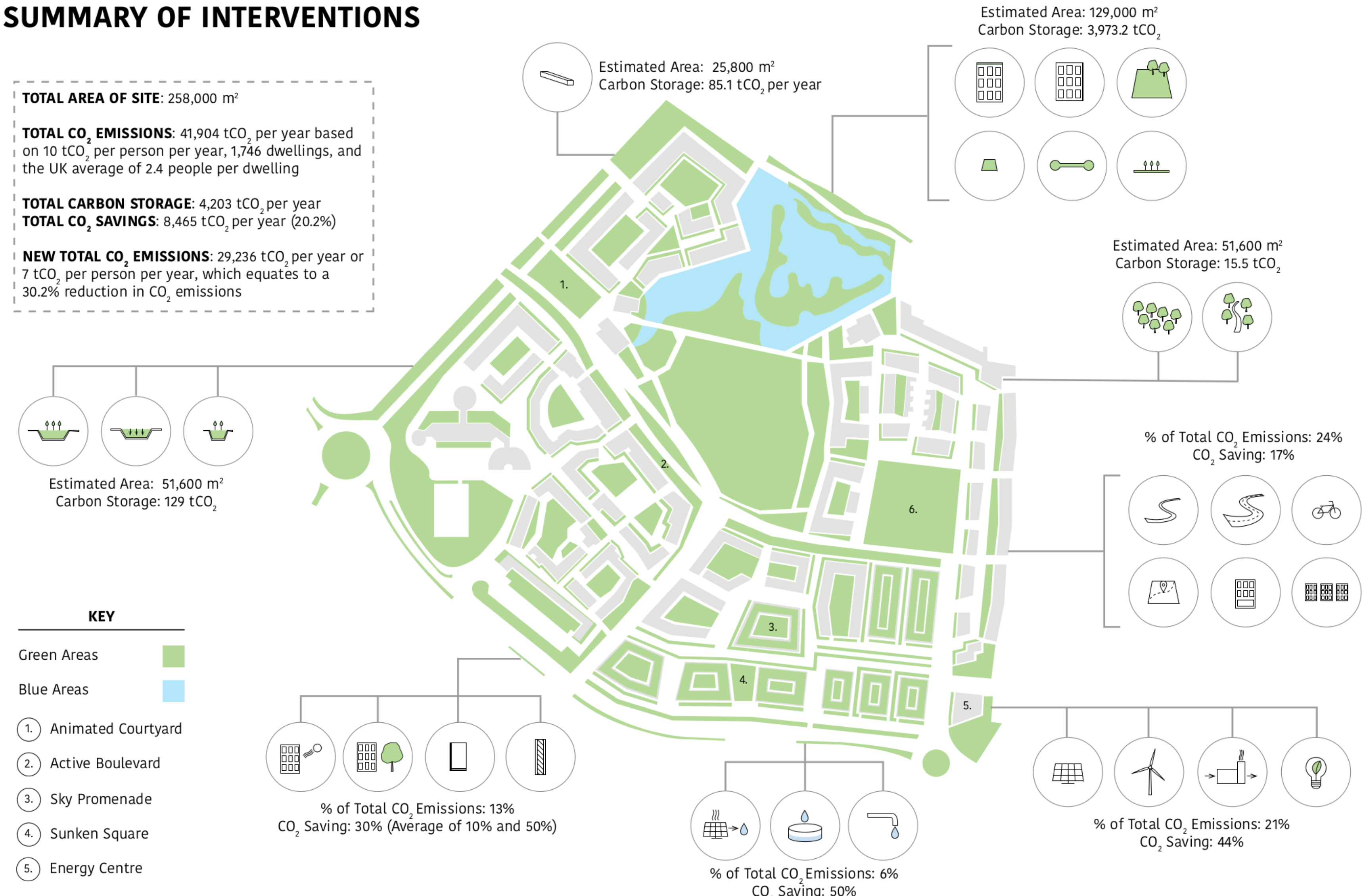

Figure 58. An estimation of the total carbon storage, total CO_2 saving, and total CO_2 emissions at GMV following the implementation of the design tool-kit.

SUMMARY OF FINDINGS

How can sustainable urban design be utilised to enhance carbon storage in urban areas and mitigate climate change?

The application of the design tool-kit to GMV has shown that sustainable urban design can successfully enhance carbon storage and reduce CO_2 emissions at the building, street and neighbourhood scale of low-carbon developments. A reduction in CO_2 emissions from 10 to 7 tCO_2 per person per year was achieved at GMV, which is a comparable figure to both BedZED, South London (7.7 tCO_2 per person per year) and Upton, Northampton (8 tCO_2 per person per year). In addition to this, the threat of flooding was minimised through a range of multifunctional measures, thereby addressing multiple issues related to climate change. However, net zero carbon emissions were not achieved as a result of the interventions implemented at the site. Evidentially, a reduction in CO_2 emissions in other sectors outside the built environment needs to take place, and the use of natural resources must be minimised, in order to meet the government's target. Still, it must be noted that the carbon stored in vegetation eventually enters the soil, and so the carbon storage estimated at GMV will increase over time. Importantly, this project has allowed a previously intangible problem to be quantified, which makes the design tool-kit an attractive tool to practitioners. Hence, it can be applied to new and existing neighbourhoods around the world, with consideration of the local context, to enhance carbon storage and reduce CO_2 emissions. Ultimately, the design tool-kit can assist in the fight against global climate change.

FUTURE RESEARCH

To advance current knowledge on low-carbon neighbourhoods, future research should focus on quantifying the potential of various aspects of the built environment to store carbon. The ability of urban areas to store carbon is still poorly understood, and very little research has been carried out on quantifying carbon storage, which is preventing progress in the development of low-carbon neighbourhoods. It is hoped that this major research project can inspire practitioners to pursue carbon storage in urban areas, as “sinking the city” may be key to saving the planet.

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