

Pilot Project

Green Roof Audit and Feasibility Study

Brighton and Hove City Council

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1 Introduction

EXPERTISE

- 1.1 The following document has been prepared by Ben Kimpton (Senior Ecologist - The Ecology Consultancyⁱ, The Green Roof Consultancyⁱⁱ) with support from Matthew Thomas (former Ecologist - Brighton & Hove City Council), James Farrell (The Environment Agencyⁱⁱⁱ, Chair - Brighton and Hove Building Green^{iv}), Dusty Gedge (Founder - Livingroofs.org^v, Director - The Green Roof Consultancy) and Lee Evans (Director - Organic Roofs^{vi}). It summarises a pilot project, carried out in 2012/13, to explore the potential for retrofitting green roofs in Brighton and Hove and to quantify the ecosystem services benefits this would yield.

BACKGROUND

- 1.2 The pilot project is a continuation of work by a number of individuals to increase understanding of the importance of green roofs as part of the urban green infrastructure (GI) tool-kit. The planning policy context is currently provided by nature conservation policies in the Local Plan 2005 and the Draft City Plan and by Supplementary Planning Document 'Nature Conservation and Development^{vii} (SPD 11) but it is clear that the benefits of green roofs go well beyond nature conservation and that a broader and more ambitious policy base may be warranted.
- 1.3 Brighton and Hove is included in the South Downs Way Ahead Nature Improvement Area (NIA). There are currently 12 NIAs in England, each one aiming to establish a coherent and resilient ecological network based on opportunities for restoring and connecting nature on a landscape scale. The Brighton and Hove section of the South Downs Way Ahead NIA includes urban green space and even buildings right inside the urban area, presenting an unusual opportunity for landscape scale conservation initiatives. The vision is for "a better connected and inspirational chalk ecosystem, sustainably managed to enhance biodiversity and people's well-being for now and the future". Objectives relevant to the pilot project include:
- The 'Town to Down' initiative demonstrating the value of ecosystem services to local communities.
 - Bringing the chalk downs into Brighton & Hove urban environments through creation of a green network (including chalk habitats).

- 1.4 Working as part of a broad partnership, Brighton and Hove City Council has recently had its application for designation of Brighton, Hove, much of Lewes District and surrounding downland as a UNESCO World Biosphere Site¹ accepted. The application has a strong GI element and good potential links to this pilot project.
- 1.5 This project has been modeled on recent work by ‘Greening The BIDs’ which has seen GI audits carried out across London’s Central Activities Zone. Greening The BIDs was funded by The Greater London Authority^{viii} through the Drain London Project^{ix} and the main driver for this work has been to reduce surface water flooding. It has been a catalyst for new and retrofit GI in London with green roof, green wall and rain garden projects having been recently delivered in Victoria, Westminster, Lambeth, Southwark and Tower Hamlets etc. Off the back of ‘Greening the BIDs’ the UK’s first GI Audit Best Practice Guide for urban areas was published^x.

¹ Brighton and Lewes Downs World Biosphere Reserve <http://biospherehere.org.uk/>

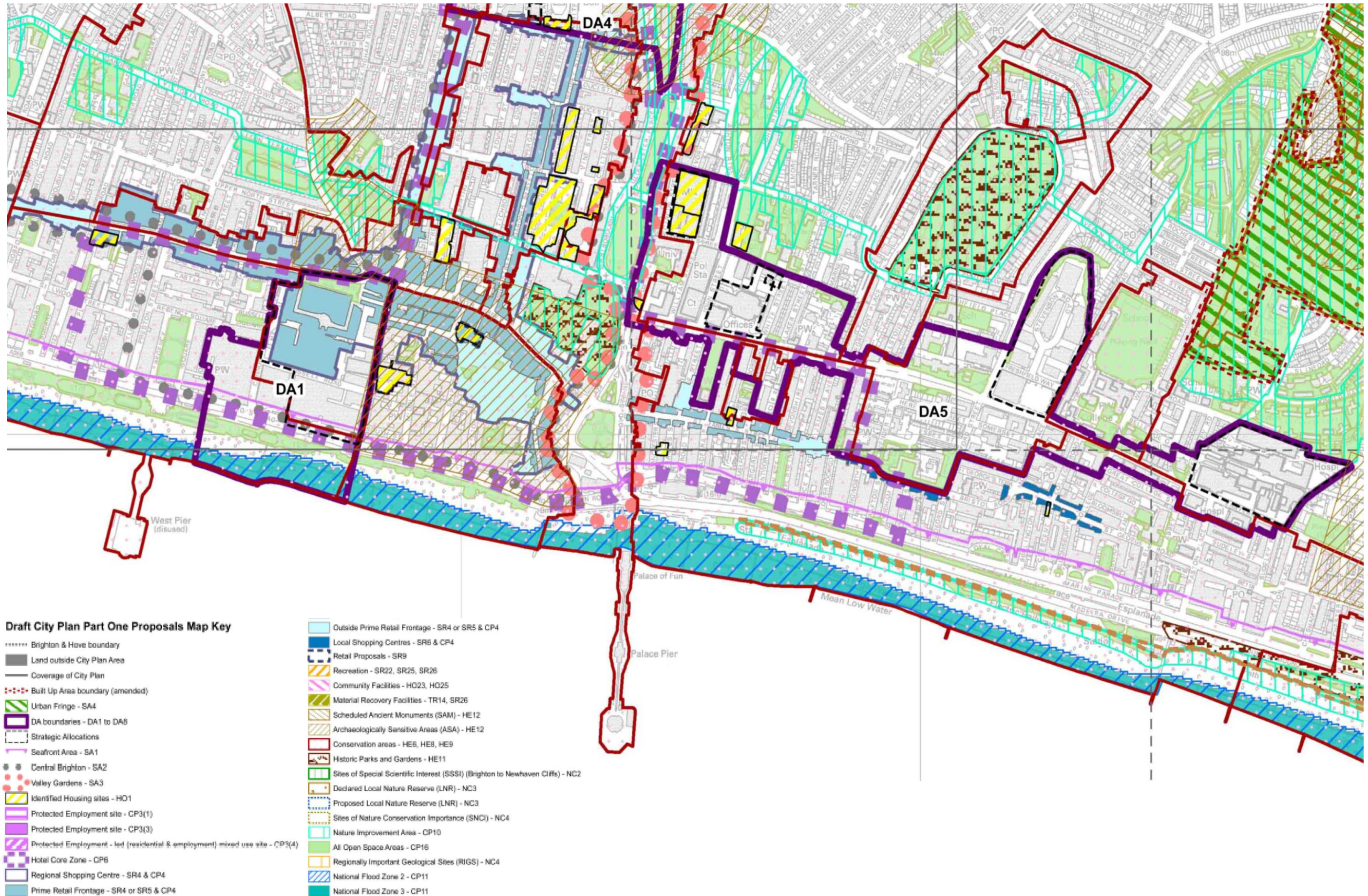
2 Methodology

SAMPLING

2.1 The center of Brighton was chosen for the green roof audit and feasibility study. It comprises a 3km x 3km zone covering the following nine Ordnance Survey (OS) grid squares TQ3003-3203, TQ3004-3204 and TQ3005-3205 and has a total area of 900 hectares (ha). This area stretches from the coast (West Pier) north towards Dyke Road (Dyke Road Park), east to Bear Road (Brighton Cemetery) and south to the coast in Kemp Town (Duke's Mound). This area was chosen for the following reasons:

- It includes the heart of Brighton's Central Business District, whilst also including a range of other land-uses such as major transport infrastructure, open space, residential and industrial.
- It is identified as a main area for change in Brighton and Hove Local Plan (2005) as it includes Strategic Allocations such as Development Areas (DA1, DA4, DA5) and Identified Housing Sites (HO1) (see Map 2). This creates special opportunities for the creation of new green roofs as well as retrofit options.
- It includes land within and adjacent to the NIA (CP10) (see Map 2).
- It includes low lying ground running from the Lewes Road and London Road to the Old Steine which is identified by the Environment Agency as being the main area susceptible to surface water flooding (see Map 1).

Map 2: Extract from Brighton and Hove Draft City Plan showing extent of NIA in Central Brighton



Map 1: Areas Susceptible To Surface Water Flooding. Adapted from Environment Agency Easimap. Ordnance survey licence number 100024198



- 2.2 The selected sample area was divided into smaller squares, each 300m x 300m in size and covering a total area of 9ha. Each square was printed out onto one A3 sheet at a scale of 1:1,000 to create a series of base maps. Excluding the coastal zone a total of 85 sheets were created.
- 2.3 Of these it was decided to use Sheet 24 as the pilot project as it has a high number of individual flat roofs with a diverse range of building types, including existing green roofs. It also includes part of the New England Quarter where major regeneration took place between 2004 and 2008.

FLAT ROOF AUDIT AND GREEN ROOF FEASIBILITY STUDY

- 2.4 The audit and feasibility study was a desk-based exercise with the results digitised using GIS software ESRI's ArcView and using OS Mastermap as the base map. This format is

compatible with GIS programmes run by other organisations and can therefore be readily adapted for future projects.

- 2.5 The first stage was to create a flat roof baseline dataset. As the GIS data for individual building footprints could not be separated from other themes (roads, structures etc.) a universal code was applied to every individual drawn object on the maps.
- 2.6 This data set was then reviewed to identify all flat roofs present and to check that codes were correctly matched to them. This was carried out using the on-line aerial mapping service Bing Map’s ‘bird’s eye feature’^{xi} and Google Earth^{xii}. Where the extent of a flat roof was different to the matched polygon, differences were marked by hand onto hard copy maps. Where additional flat roofs were present, as was commonly the case with more complex roof structures, these were also marked onto the maps along with new codes for each extra flat roof. The results were then inputted into the GIS environment to create a revised and more accurate flat roof data set. Only codes relating to flat roofs were retained, with these renumbered sequentially from 0 upwards to give flat roof ID numbers.
- 2.7 Using the same on-line mapping tools described above each flat roof was then assessed for its potential to be greened based on the building/roof structure and build-up of materials. A key part of this process was applying a scoring system developed by Dusty Gedge of The Green Roof Consultancy during The Greening the BIDS project and London’s Living Roofs and Walls Technical Report. The Table below is an overview of how the scoring is applied but other factors also influenced the process, such as roof size, volume of plant, age, aspect and previous knowledge of the building in question.

Table 1: Scoring System for Determining Potential to Retrofit Green Roofs

Score	Definition
0	Flat roof with potential, but unable to meet the Green Roof Organisation ^{xiii} (GRO) standard of a recommended minimum substrate depth of 60mm.
1	Warm roof likely to be able to support a lightweight thin-layered green roof system with that meets the GRO standard
2	Inverted or warm roof likely to be able to support a full biodiverse green roof with substrate depth 80-150mm

Table 1: Scoring System for Determining Potential to Retrofit Green Roofs

Score	Definition
3	Inverted roof or warm' roof likely to be able to support a full biodiverse green roof, semi-intensive or intensive green roof.

LIMITATIONS

- 2.8 The original objective was to audit the block made up by Sheets 14, 15, 24 and 25 (selected from the 85 sheets covering central Brighton) and a residential area (terrace housing) adjacent to Sheet 24. Address point data was not however available to generate a unique flat roof ID number for each flat roof. Furthermore, individual building footprints could not be separated from polygons relating to other mapped features, resulting in 67,200 labels. At an early stage in the project the process of generating a flat roof data set was identified as being much more intensive than other audits of this nature and therefore the pilot project was limited to the auditing of only one Sheet i.e. Sheet 24.
- 2.9 Ground-truthing can be useful to collect information on buildings/roofs, particular where the coverage/quality of aerial images is poor. This stage was not carried out as part of this audit.
- 2.10 Figures on the benefits (ecosystem services) provided by green roofs are based on external case studies from other cities *v/z.* North America. They do not account for the different environmental conditions that cities experience, which will create variation in the benefits derived by green roofs. Furthermore, some of these case studies use modeling to assess the benefits of green roofs and are not based on empirical data collected from green roofs in the cities being studied.
- 2.11 The audit provides a crude estimate of the potential flat roof area that could be greened in the center of Brighton, extrapolated from a smaller sample area. The figures on ecosystem service provision from external case studies have then been used to further extrapolate the benefits of green roofs in Brighton, should the potential area identified in the audit be achieved. This approach is intended to encourage the use of green roofs in Brighton as part of a wider GI model and should not be used as a city-specific business case for their implementation.

3 Benefits

3.1 Green roofs are an integral part of urban GI. They can deliver multiple benefits (or ‘Ecosystem Services’) to Brighton and Hove residents, businesses and tourists.

ECOLOGICAL

- Habitat for a range of native and non-native plant species.
- Cover, foraging and nesting opportunities for both common and rare species of insect, bird and bat. In Switzerland even reptiles are benefiting from green roof installation.
- Mitigation for the loss of habitats during development, such as flower rich grassland and brownfield (wasteland) which can both qualify as habitats of principal importance for the conservation of biodiversity in England.
- Opportunity to bring chalk grassland into the City and link to the South Downs National Park as part of environmental education.
- Contribution to landscape-scale initiatives to promote biodiversity across the City, such as the Greenway Network, NIAs and Biodiversity Opportunity Areas^{2 xiv}.
- Provides stepping stones for migratory species, reducing problems of fragmentation.

CLIMATE CHANGE MITIGATION AND ADAPTATION

- Important role in wider storm water management strategy, reducing storm water runoff, surface water flooding and demand on sewer systems at peak flow periods.
- Important source control mechanism as part of Sustainable Drainage Systems (SuDS) and Water Sensitive Urban Design (WSUD) which can include rainwater harvesting.
- Improve water quality by filtering pollutants and moderating temperature of water leaving roofs.
- Reduction of the Urban Heat Island Effect (UHIE).

² Biodiversity Opportunity Areas (BOAs) represent a targeted landscape scale approach to conserving biodiversity, identifying opportunities to expand, link and buffer key sites. There are 75 BOAs across Sussex.

- Improvement to air quality by capturing gases, pollutants and atmospheric deposits.
- Reduction of asthma related illness that can be triggered by pollution and UHIE.
- Decreasing production of CO2 and other pollutants released into the air by reducing our heating/cooling demand in buildings and through photosynthesis by plants.

SOCIAL

- Visual/amenity value.
- Improved access to natural green space.
- Improved health and well-being through physical and passive recreation.
- Private food growing space, with large roofs having the capacity for urban agriculture.
- Promoting social cohesion and providing central hubs for community initiatives such food growing/pop-up cafes, performance space, gardening/nature projects.
- Noise reduction.
- Environmental education (and research opportunities) particularly if green roofs are on educational facilities or publically accessible roofs.

ECONOMIC

- Improved building energy budgets i.e. aiding energy efficiency.
- Reducing cost of climate change such as increased cooling (air conditioning), surface water flooding incidents, increased insurance premiums.
- Increased property value (both sale and rent price) due to improvements to appearance and efficiency of the building.
- Improved working environment for building users resulting in lower rates of absenteeism and employee/tenant turnover.
- Regeneration of urban zones, improving investment opportunity.
- Green roofs can increase a building's marketability.
- Better waste management by extending roof material life-cycle.
- Promotion of local green roof businesses, horticultural/landscape industry etc.

- Waste diversion – prolonged waterproofing membranes, use of recycled materials in green roof substrate (crushed brick etc.), prolonged service life of heating, ventilation, and air conditioning systems through decreased use.
- Job opportunities in green roof industries such as product manufacturing, plant production (horticulture), design, installation, and maintenance.
- Decreased demand for health care due to improved health and wellbeing and environmental conditions (air, water etc.)

4 Summary of Findings

SHEET 24

- 4.1 Initial findings show both the high potential for retrofitting green roofs but also missed opportunities at roof level during the 2004-2008 regeneration of the New England Quarter. The number of traditional (climbing) green walls is however noteworthy and sets a good precedent for future development in the City.
- 4.2 Flat roofs occupy approximately 25% of the pilot area – i.e. 2.3ha and have been categorised in Table 2 below which is also represented on Map 3).

Table 2: Analysis of Flat Roofs With Green Roof Potential Within Pilot Area

Score	Retrofit Potential	Area (ha)	% Total Flat Roofs	% Total Area i.e. 9ha
0	Low	0.155638	6.87817944	1.729311111
1	Moderate	0.956726	42.2810182	10.63028889
2	High	0.464885	20.5448698	5.165388889
3	Highest	0.68553	30.2959326	7.617
	TOTAL	2.262779	100	25.14198889

Map 3: Flat Roof Location and Potential for Greening Across the Pilot Project Area



1	2	3	4	5	6	7	8	9	10
11	12	13	14	15	16	17	18	19	20
21	22	23	24	25	26	27	28	29	30
31	32	33	34	35	36	37	38	39	40
41	42	43	44	45	46	47	48	49	50
51	52	53	54	55	56	57	58	59	60
61	62	63	64	65	66	67	68	69	70
71	72	73	74	75	76	77	78	79	80
				81	82	83	84	85	

- 4.3 42% of all flat roofs in the pilot area have moderate potential, meaning they could be retrofitting with a lightweight thin-layered green roof system that meets the minimum GRO standard of 60mm substrate depth. 21% of flat roofs have high potential i.e. retrofitting of a green roof able to support a full biodiverse green roof with substrate depth of between 80-150mm. 30% of flat roofs have the highest potential in terms of loading capacity, able to accommodate a full biodiverse green roof or more 'gardenesque' green roof. The latter figure is however inflated by the single large area of Brighton Station Upper Level Car Park (0.57ha) being included in the figure.
- 4.4 Excluding Brighton Station Car Park approximately 50% of the total flat roof area has potential for a biodiverse green roof. This equates to 13% of the total area for Sheet 24. This figure is in line with findings from the 'Greening the BIDS' project in London's Central Activity Zone. Such roofs should always be prioritised for action in preference to lightweight green roof systems, due primarily to their increased substrate depth and planting regime they can deliver more benefits (ecosystem services) to the City.

EXTRAPOLATION

- 4.5 By using the findings from Sheet 24 it is possible to estimate the potential area of biodiverse green roofs that could be delivered across the wider project area. The wider project area includes 85 Sheets covering an approximate area of 765ha.
- 4.6 In order to 'scale-up' the pilot project it is necessary to adjust the findings to accommodate for variation in land-uses. Sheet 24 is a good representation of mixed-use with transport infrastructure, commercial, education and multi-residential buildings all present. Significant parts of the wider project area are however dominated by public green space and/or residential streets which do not have the same number, type and size of flat roofs that are found on Sheet 24.
- 4.7 For example, in the Hanover Area the majority of residential streets comprise terrace houses that have pitched roofs unsuitable for greening. Dwelling density has however led to a high number of extensions, dormers and sheds and subsequently a high number of flat roofs, although these are typically small and structurally are less likely to accommodate a full biodiverse green roof when compared to other building types.

- 4.8 Using on-line mapping tools such as Promap (allowing the measurement of areas using aerial photographs) it is was calculated that ground floor extensions occupy approximately 10% of the footprint of each terrace house and these are present on approximately 50% of properties. Due to their smaller size dormers and sheds were excluded from this exercise. As a conservative estimate it is likely that only 50% of extensions will have the loading sufficient for a biodiverse green roof with substrate depth greater than 60mm. Based on the Hanover area, 2.5% of residential streets (by area) therefore have potential for retrofitting green roofs. Overall it is estimated that approximately 30% of the wider project area comprises residential streets (dominated by terrace housing). This has an approximate area of 230ha which equates to a total flat roof area of 6ha with potential for retrofitting biodiverse green roofs.
- 4.9 It is estimated that approximately 15% (115ha) of the wider project area comprises public open space. This area has been excluded from any calculations as buildings are generally absent.
- 4.10 Excluding residential areas and open space, 55% of the wider project area i.e. 420ha remains. Applying the findings from the pilot project to this area (i.e. the 13% rule, see paragraph 20) a total flat roof area of 55ha has potential for retrofitting biodiverse green roofs.
- 4.11 When all of these variations in land-use are taken into consideration, approximately 61ha of flat roofs across the wider project area have potential for retrofitting biodiverse green roofs. This equates to approximately 8% of the total area.

5 Individual Ecosystem Services

ENERGY BALANCE – SUMMER COOLING

- 6.1 In Toronto's The Environmental Benefits and Costs of Green Roof Technology (2005)^{xv} it was estimated that the direct savings through reduced energy costs for cooling as a consequence of city wide roof greening would be in the order \$22 million, equivalent to 4.15kWh/m² per year³. This has a CO₂ emission savings of 1.7kg/m² per year. There would also be a reduction in peak demand in the order of 114.6MW leading to fossil fuel reductions in the region of 56,300 metric tonnes per year.
- 6.2 Applying the figure on kW/h savings to the wider project area in Brighton (but excluding domestic properties that do not typically use air conditioning) it is estimated that 2.3MWh could be saved on cooling costs per annum. Taking an average fuel cost of £0.20/kWh this is the equivalent of saving £456,500 and 935,000kg of CO₂ emission per year.

ENERGY BALANCE – WINTER HEATING

- 6.3 A study of domestic buildings with green roofs in north-east Germany suggests that there is a 3-10% winter saving on fuel bills^{xvi}. The results of five years study suggest that there is a maximum saving of 6.8kWh/m² [equivalent of 1.5kg/m² CO₂] and a minimum saving of 2.0kWh/m² [equivalent of 0.44kg/m² CO₂] during the winter. As this figure depends on the roofs insulation properties, which is affected by how wet the roofs are, a conservative approach has been taken. Applying the lower figure to the wider project area in Brighton (including domestic properties) it is estimated that 1.2million kWh could be saved on winter heating costs per annum. This equates to £244,000 and 107,000kg of CO₂ emissions per year.

³ These findings are based on two assumptions. Benefits on a citywide basis were calculated based on the assumption that 100% of available green roof area would be used. The available green roof area included flat roofs on buildings with more than 350m² of roof area, assuming that at least 75% of the roof area would be greened. The total available green roof area citywide was determined to be 5,000ha (50m m²) which is 8% of Toronto's total land area.

The report also presents its assumptions used in calculating City benefits as the minimum design criteria for a green roof to achieve the stated benefits. The key considerations were that the roof system be 'extensive', that it cover a significant proportion of the roof, have a maximum storm water runoff coefficient of 40%, and have a growing medium depth of at least 150mm, where structural loads permit. Green roofs with shallower growing media could be used on roofs where structural loading does not permit the 150mm depth, although it would be recognised that the benefits would be reduced.

- 6.4 It is important to stress that the above figures for costs savings on energy balance present a very conservative approach as can be highlighted by a case study of a building in Canary Wharf, London. This 850m² retrofitted green roof achieved an estimated reduction of 25,920kWh [11.46 tonnes of CO²] a year through a reduction in both heating and cooling costs. Taking an average fuel cost of £0.20/kWh this is the equivalent of saving over £5000 per year or 30.5kWh per m² of green roof.

URBAN HEAT ISLAND EFFECT

- 6.5 Computer modelling by the New York Heat Island Initiative^{xvii} has predicted that greening 50% of roofs within this metropolitan area would lead to between 0.1-0.8°C reduction in average summertime surface temperatures.
- 6.6 In Toronto's The Environmental Benefits and Costs of Green Roof Technology it was estimated that the effect of greening the cities rooftops would lead to a 0.5-2°C decrease in the UHIE. A reduction of this magnitude would, lead to indirect energy savings citywide from reduced energy for cooling of \$12million, equivalent to 2.37kWh/m² per year.
- 6.7 Applying the same figure to the wider project area in Brighton (but excluding residential areas that are less likely to suffer from the same extremes of UHIE when compared to office/commercial space) it is estimated that 1.3million kWh could be saved on cooling costs per annum. Taking an average fuel cost of £0.20/kWh this is the equivalent of saving £260,700.

STORM WATER ATTENUATION

- 6.8 Green roofs can retain higher amounts of summer rainfall (approximately 70-80%) compared to winter rainfall (approximately 25-40%) due to the roofs already being partly saturated. The amount of water a green roof can hold is however dependent on many factors including vegetation, depth and type of substrate and time and intensity of rainfall event. By incorporating green roofs there will be a reduction in the amount and cost of the overall drainage infrastructure required to serve urban development. These benefits will be highest for new build schemes as drainage infrastructure can be designed (scaled back) pre-development to account for the reduced demand.

- 6.9 The Environment Agency will normally require that, when considering a 1 in 100 year rainfall event, that the developed rate of runoff into a watercourse should be no greater than the undeveloped (i.e. greenfield) runoff rate for the same event. The purpose of this is to retain a natural flow regime in the receiving watercourse and not increase peak rates of flow for events greater than 1 in 100 years. SuDS, which includes green roofs as a source control mechanism, can play an important part in achieving greenfield runoff rates.
- 6.10 A study in Washington, DC by Deutsch et al (2005)^{xviii} estimated that greening 4% of the total land area (29% of the total building footprint)⁴ would provide an additional 6.96m² of green roofs that could store 5.62m³ of storm water annually. This is the equivalent of 0.81m³ of storm water retention per m² of green roof per annum. The annual volume captured equates to 5.8% of citywide runoff, would result in a 28% reduction in the total number of combined sewer overflows (CSOs) and avoid 1.26m³ of raw sewerage from entering river systems. This would reduce infrastructure costs to the city's long-term control plan (LTCP) (estimated capital cost of 1.9 billion dollars) by \$110m assuming a 5.62m³ reduction in the 97m³ of storm water that are managed annually demonstrated above. As each m³ of storm water retention has a cost reduction of \$19.6 (£12.70), each m² of green roof saves \$15.9 (£10.30).
- 6.11 For the Detroit metropolitan area, assuming a retention rate of 65% of annual precipitation (0.84m for Detroit), greening 10% of rooftops (54.2m²) would retain approximately 30m³ of water. Clark *et al* (2008)^{xix} have taken the estimated costs of the LTCP (\$3.5 billion) and translated this as a reduction of \$114m, suggesting substantial opportunity to invest in aboveground roof infrastructure. This is equivalent to 0.55m³ of storm water retention per m² of green roof per annum. As each m³ of storm water retention has a cost reduction of \$3.85 (£2.50), each m² of green roof saves \$2.1 (£1.37).

⁴ This study assumes that 80% of the footprint of buildings greater than 10,000ft² (930m²) would be greened and that 80% of these green roofs would be extensive (50-150mm) and 20% would be intensive (greater than 150mm). 85% of the green roofs would be retrofitted and 15% new build. It takes a combined average annual water retention figure for both intensive and extensive roofs of 69%.

Table 3: Water retention in green roofs (based on 650–800mm annual rainfall). Extracted from FLL (German Landscape Research, Development and Construction Society)

Green Roof Type	Substrate Depth (mm)	Vegetation	% Average Water Retention per year	Co-efficient
Extensive	20-40	Moss/sedum	40	0.6
	40-60	Sedum/moss	45	0.55
	60-100	Sedum/moss/herbs	50	0.5
	100-150	Sedum/herbs/grass	55	0.45
Intensive	150-200	Grass/herbs	60	0.4
	150-250	Lawn/shrubs	60	0.4
	250-500	Lawn/shrubs	70	0.3
	500+	Lawn/shrubs/trees	90+	0.1

- 6.12 Recent work by Micro Drainage and the University of Sheffield now enables a green roof to be modelled as part of SuDS. Their findings show that an interception value of 5% of the green roof substrate volume, i.e. the volume of water that falls on the roof but does not leave it, would be a reasonable average for UK green roofs⁵. Applying an interception storage of 5% to the 61ha of biodiverse green roofs that could be retrofitted across the wider project area in Brighton (taking an average substrate depth of 115mm) would equate to 3507.5m³ of storm water attenuation.
- 6.13 Brighton receives on average 800mm (0.8m) of rainfall per annum. Assuming a retention rate of 50% of annual precipitation (from an average substrate depth of 100mm), then retrofitting 61ha of biodiverse green roofs across the wider project area in Brighton would retain 244,000m³ of water.

AIR QUALITY

- 6.14 The potential benefit of green roofs to remove nitrogen dioxide (NO₂), sulphur dioxide (SO₂), carbon monoxide (CO), particulate matter (PM10), and O₃ (ozone) have been studied in several US cities using both computer modelling and experimental plant studies. Peck (2003)^{xx} estimated that greening 6% of Toronto would reduce the UHIE by 1 to 2°C preventing 0.62 MT (Mega tons) of indirect greenhouse gas emissions.

⁵ As high levels of antecedent rainfall can limit the potential of a green roof to provide attenuation and storage, it was decided to model the retention expected after a two day antecedent dry weather period i.e. the available water storage is based on zero rain falling on the roof for two days prior to testing.

- 6.15 A summary of modeled air pollution mitigation scenarios in Toronto, Ontario and Washington, DC (Clarke *et al*, 2008) shows the estimated annual removal (uptake) of all pollutants by green roofs (per ha) ranged from 71.95kg (Toronto) to 83.27kg (Washington, DC) when an equal mix of evergreen shrubs and grasses are planted at roof level. This equates an all pollutant uptake of between 0.0072 – 0.0083kg/m²/y. From experimental plant studies in Toronto, the mean NO² uptake value was found to be 0.0015kg/m²/y with Washington, DC similar at 0.0011kg/m²/y.
- 6.16 These figures are supported by Deutsch et al (2005) that show by greening 6.7% of Washington DC (equivalent of 74,970,000m²) 58,000kg of pollutants will be removed annually. This is the equivalent of 0.0088kg/m²/y. Most interestingly this was calculated to represent the equivalent of having 93,500 street trees (in term of NO_x reduction).

EXTENDED ROOF LIFE PROTECTION OF WATERPROOFING

- 6.17 Green roofs extend the life of waterproofing membranes by protecting them from climatic (temperature) extremes, UV light & mechanical damage. The waterproof membrane on a traditional roof will normally need replacing after 15-20 years, whereas in countries with a long established green roof industry such as in Germany, a life span of between 30-40 years is designed for (Snodgrass & MacIntyre, 2010)^{xxi}. The life span of traditional roofs such as single-ply (25 years) and bituminous (30-35 years) is reported as higher in other literature (GLA, 2008) but it is widely expected that a doubling of the waterproof life span is achieved through installing a green roof.

6 Combined Ecosystem Services

- 7.1 The studies outlined in Section 5 demonstrate some of financial benefits derived from green roofs for individual ecosystem services. Toronto's 2005 The Environmental Benefits and Costs of Green Roof Technology took this one step further in demonstrating the derived cost benefits at a municipal/city level. The following table summarises this data and converts it into a cost (£) per m² of green roof, based on a 2005 exchange rate of \$1.79 to £1.
- 7.2 In Toronto the initial cost savings for installing green roofs citywide equates to £3.50 per m². This accounts for the combined ecosystem benefits derived from building energy, combined sewer overflow, storm water and UHIE (see Table 4 below).
- 7.3 The annual cost savings for installing green roofs citywide equates to £0.41 per m². This accounts for the combined ecosystem benefits derived from air quality, building energy, combined sewer overflow and UHIE (see Table 4 below). Taken over a period of 30 years (a conservative estimate of the life span of the green roof) this equates to long term citywide benefits of £12.30 per m².

Table 4: Summary of municipal level environmental benefits of green roof implementation in the City of Toronto covering 5,000ha

Ecosystem Benefit	Initial Cost Saving City Wide (\$m)	Equivalent (£m)	£ per m ²	Annual Cost Saving City Wide (\$m)	Equivalent (£m)	£ per m ²
<i>Air Quality</i>						
Impacts of reduction in CO, NO ₂ , O ₃ , PM10, SO ₂				2.5	1.397	0.03
<i>Sub-total</i>				2.5	1.397	0.03
<i>Building Energy</i>						
Savings in annual energy use				21	11.732	0.24
Cost avoidance due to peak demand reduction	68.7	38.379	0.77			
Savings from CO ₂ reduction				0.563	0.315	>0.01
<i>Sub-total</i>	68.7	38.379	0.77	21.563	12.046	0.24
<i>Combined Sewer Overflow (CSO)</i>						
Storage cost avoidance	46.6	26.034	0.52			
Reduced beach closures				0.75	0.419	>0.01
<i>Sub-total</i>	46.6	26.034	0.52	0.75	0.419	>0.01
<i>Storm water</i>						
Alternate best management practice cost avoidance	79	44.134	0.88			
Pollutant control cost avoidance	14	7.821	0.16			
Erosion control cost avoidance	25	13.966	0.28			
<i>Sub-total</i>	118	65.921	1.32			
<i>Urban Heat Island</i>						
Savings in annual energy use				12	6.074	0.13
Cost avoidance due to peak demand reduction	79.8	44.581	0.892			
Savings from CO ₂ reduction				0.322	0.18	>0.01
<i>Sub-total</i>	79.8	44.581	0.892	12.322	6.884	0.14
	313.1	174.92	3.50	37.135	20.746	0.41

7 Conclusions

- 8.1 By using the results from the pilot area and extrapolating for different land-use types across the wider project area it has been estimated that biodiverse green roofs could potentially be retrofitted across 61ha of flat roof. This is the equivalent to 8% of the total area of central Brighton chosen for this audit and feasibility study.
- 8.2 By taking conservative figures on the benefits (ecosystem services) derived from green roofs across an area this size it is estimated that 2.3MWh could be saved on cooling costs for buildings (air conditioning) per annum and 1.2million kWh on winter heating costs per annum. Greening roofs would also reduce the Urban Heat Island Effect potentially providing an additional saving in cooling costs in the region of 1.3million kWh per annum.
- 8.3 In terms of SuDS benefits it is estimated that 61ha of biodiverse green roofs could attenuate 3507.5m³ of storm water when applying an interception storage of 5% and average substrate depth of 115mm. If however you assume a retention rate of 50% of annual precipitation (from an average substrate depth of 100mm), then 244,000m³ of storm water could be stored at roof level across the wider project area. This could have a significant combined effect in reducing the City's infrastructure costs and demand on sewer systems at peak flow periods.
- 8.4 The estimated annual removal (uptake) of all pollutants by 61ha of green roofs, when an equal mix of evergreen shrubs and grasses are planted, could be approximately 4400kg (4.4 tons) per annum.
- 8.5 Where new build green roofs, or flat roofs with potential to be retrofitted, are present within or adjacent to Brighton and Hove's section of the South Downs Way Ahead NIA there is an opportunity to bring the chalk downs into Brighton & Hove urban environment at roofscape in the form of carefully designed biodiverse green roofs.

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