University of Brighton

A Multi-Criteria Decision Making Framework for Airspace Development Opportunities: The BrightNest Project.

Presented by

Michael Williams

A thesis submitted to the University of Brighton in partial
fulfilment of the requirements for the degree of

MSc GIS and Environmental Management

2019, August

DECLARATION AND WORD LENGTH

I declare that the research contained in this thesis, unless otherwise formally indicated within the text, is the original work of the author. The thesis has not been previously submitted to this or any university for a degree, and does not incorporate any material already submitted for a degree.

Signed: Michael Williams

Date: 28/08/2019

Word Count: 16,256

Abstract

In response to the United Kingdom's housing pressures, the requirement for a low cost, alternative housing scheme with sustainability as a core value has never been greater. The University of Brighton's BrightNest project was designed to these meet these requirements. It's recycled shipping container structure, coupled with a self-sustaining solar power design, allows for fast construction upon the rooftops of Brighton. With BrightNests proof of design nearing; the next big question for the project is its application potential. Analysis of physical and social criteria central to the success of the project would quantify BrightNest's development potential within Brighton. This will be achieved through a two phased methodology; firstly, remotely sensed LIDAR and photogrammetry datasets will be used to determine rooftops with the physical capacity for BrightNest construction. These identified sites were then ranked against 6 criteria in the second Phase of assessment, allowing the most favourable sites for BrightNest development to be determined. Phase One of the project identified 255 separate rooftops with an area suitable for development. In Phase Two these sites scored relatively well, with a positively skewed distribution and 8 sites classified within the highest suitability grouping. Upon assessment of these results, it was apparent that the modelling methodology employed was liable to processing based errors which had a notable impact upon site identification. A Sensitivity Analysis also determined that the site rankings were stable under input parameter adjustment, acting to reassure future developments to the BrightNest project. This project acts as a high-level initial investigation to the potential of the BrightNest project, whilst project feasibility was demonstrated, further detailed assessments would be required by specialists within urban planning and design. The application of this methodology to the BrightNest project has also facilitated an important contribution to the literature, with no previous work applying Multi Criteria Decision Making processes to urban airspace development.

Acknowledgements

I would like to acknowledge the School of Environment and Technology for 4 years of the highest standard of learning and provision of countless personal development opportunities. In particular, I would like to thank Dr Niall Burnside and Dr Matthew Brolly their excellent guidance and support over this period. Finally, I would like to thank my family for their support over a very testing year.

Contents

Figures

Tables

1 BrightNest Introduction

The United Kingdom's housing status is facing scrutiny from public and politicians alike. With the Office of National Statistics (ONS) predicting that the UK will miss its 2018/2019 housing target by 120,000 homes; the situation is being linked to further failings within mental health (Shelter.org, 2017) homelessness (Fitzpatrick & Pawson, 2016) and suicide (Mind.org, 2017).

'BrightNest' is a University of Brighton led project which is aimed at providing a solar-powered prefabrication roof-top apartment. The goals of the project are to design a carbon negative building, employing circular economy principles and locally recycled and sourced materials to show how waste and recycled materials can be used to create sustainable spaces (BrightNest.eu, 2018). The design centres on an ability to be flat-packed and transported within a single shipping container, lowering transportation and construction costs. The design drawing (figure 1.1) shows the container structure which has further structural walls added both internally and externally to extend the design. Whilst further aspects of the design including an external terrace and photovoltaic array intended to self-sustain the module are illustrated in figure 1.2.

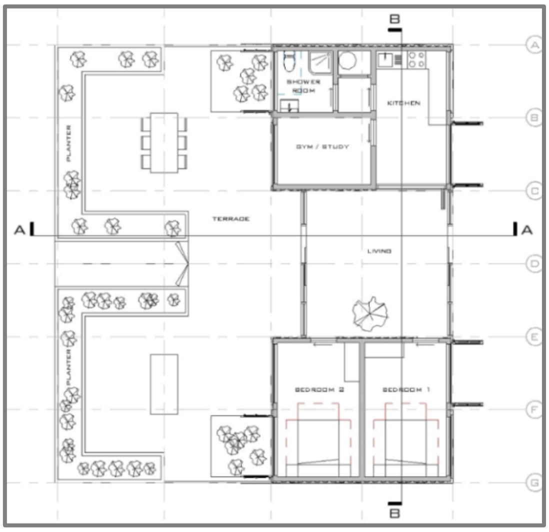

Figure 1.1: Plan drawing of the BrightNest design

Figure 1.2: Computer Aided Design conceptual drawing of the BrightNest design

In order to demonstrate applicability, a city-wide Site Suitability Analysis (SSA) which comprehensively incorporates both physical and social parameters will be required. This thesis utilised Geographical Information Systems (GIS), public domain data and secondary Remote Sensing (RS) data sources to provide the platform for analysis. This approach was identified for the project due to the reproducible and user-friendly methodologies which are greatly suited to GIS platforms (Frank & Mark, 1991).

1.1 Research Aims

1. Assess a range of physical and social parameters to quantify the development potential of BrightNest within Brighton. These outputs will act to support any future BrightNest development within the City through providing insights on project feasibility and identifying sites of greatest construction suitability.
2. Through the assessment of the BrightNest project develop a simple, high reproducible city-wide model incorporating established Site Suitability Analysis methodologies in a novel application to airspace development.

1.2 Research Objectives

- Develop a simple, computation light remote sensing analysis process to identify rooftops with the physical properties for BrightNest development.
- Apply a number of Site Suitability Analysis methodologies to rank identified sites to a set of predetermined criteria.
- Critically assess final methodology for application to the BrightNest project and potential wider application.
- Quantify the development potential of the BrightNest Project within Brighton.

2 Literature Review

The following literature review will focus on two vital aspects to the project. Firstly, the motivation behind the project, understanding the driving factors and the social needs behind the BrightNest project as well as a review of previous housing concepts. Secondly, the technical side of the study, identifying previous rooftop SSAs and the methodological approaches which were undertaken.

2.1 Project Motivation - The Housing Crisis

One of the greatest challenges facing the United Kingdom (UK) to date is the provision of affordable housing. The Office for National Statistics (ONS) reported a population growth rate of 2.9% from 2011-2015 (2017a), a rate that has pushed the Government's ability to provide basic accommodation to those in need to the centre of public opinion. In light of these nation-wide problems, commentators call the situation a crisis (Sarling, 2013; Smith *et al*., 2010), calling on the Government to provide a realistic and achievable solution.

Harold MacMillon, the UK Prime Minister in 1976 was the last official who successfully met the UKs requirement for housing (Kay, 2017). Every year since, the Government has failed to meet its housing target; with the shortage estimated to be 120,000 homes in 2020 (ONS, 2017) the socio-economic impacts of the housing crisis are set to continue.

There are a number of forcing factors which have led to the current situation. The most influential is the inevitable population growth which is set to hit 70 million by the mid-2020s (ONS, 2017). Although predictable, the issue is greatly exacerbated by the long-term trend of urban migration as people are attracted to urban hubs, leaving many rural and coastal areas with an unsustainable demographic as the younger population migrate away. Yet, demand sided factors are only problematic due to the aforementioned failures in housing supply. Urban areas are incapable of meeting these housing supplies due to the difficulties in purchasing of land plots and intense opposition to green belt expansion leaves many options for housing construction unsuitable.

These national scale problems are well portrayed within Brighton. The population is currently expected to increase to 300,000 by 2030 at a rate of 10% in 10 years (Brighton & Hove Council, 2012), with the city acting as a popular satellite settlement to 27,000 London commuters. However, the councils Housing Implementation Strategy (2014) has identified significant concerns with site viability for future developments which is likely to act as barrier to achieving housing supply targets. The lack of suitable development sites is largely the result of Brighton's geographical setting – left squeezed between the coast and the protected South Downs national park there is no available land for large developments. The City Plan requires the construction of 13,200 dwellings over a 10 year period, it is described as ambitious yet deliverable (Brighton & Hove Council, 2014) but commentators have their concerns about the affordability of delivered housing (Bright & Hove Independent, 2019).

The residual impacts of housing uncertainties are far reaching across all levels of society. There is a misconception that those affected are the low-income households, unable to afford rising rents and subsequently are forced into short term housing and homelessness. However, this shortage of affordable homes contributes to financial pressures throughout the market, with first time buyers being the latest grouping to suffer (Halligan, 2018). Regarding the most prominent impact within the UK of homelessness; charity Shelter (2018) state 320,000 people were recorded as homeless in 2018 a figure which rose by 4% from 2017 despite recent investment from government to tackle the issue.

Many believe the solution to these problems lies in the improved provision of council housing, however this would require a relief of the lower end of the housing market in order to encourage that shift from state provided to affordable housing. The described 'crisis' has led for calls for the uptake of all possible solutions to improve the provision of affordable housing, from changes standards for living legislation and new designs for housing (Netto, 2017). With significant financial backing for fresh and innovative ideas this bolsters the likely success for smaller conceptual projects such as BrightNest. has also facilitated an important contribution to the literature, with no previous work bringing

2.2 Airspace / Rooftop Development

The housing supply forces noted above are exacerbated in urban areas due to the continued trend of urban migration (GOV.UK, 2018). With the exhaustion of existing urban space and continued outward expansion met by sizeable opposition, the housing crisis has sparked real momentum into all possible alternative solutions.

One such solution, which has seen extensive interest in recent years, is the development of urban airspace. Whilst household development rights allow for homeowners to build upwards into airspace (Town and County Planning, 2015), the necessity for solutions has called for the lead of industry and local authorities in the effective development of these airspaces. Sajid Javid, speaking in 2018 highlighted the governments recognition of this potential and expressed desires to adapt existing planning regulations to allow for easier utilisation of airspace. The statement described a loosening of restrictions as long as street character and maximum roof height remains unchanged (Ministry of Housing, Communities and Local Government, 2018). With only 2% of London's annual housing target a result of airspace development (Department Communities and Local Government, 2016), a small number of comprehensive reports from large stakeholders have been produced which stress the importance of airspace development.

Knight Franks, a leading real estate agency in London produced a comprehensive which identified the airspace potential within inner city London. The 'SKYWARD' study quantified this potential at 41,000 dwellings at a value £51 Billion pounds, all without altering London's protected skyline (Knight Franks Research, 2017). The report makes a novel attempt at modelling the London View Management Framework into the analysis, ensuring that any identified airspace potential does not clash with the city's protected views and the city's character remains unchanged. In undertaking this research, Knight Franks is firstly providing competitive information for its clients but also identifies the infancy of this analysis, calling for a uniform effort between agencies to best utilise airspace potential.

Apex Airspace Development is another large stakeholder within the market whom also undertook a study assessing the potential of rooftop housing within the borough of Camden. Motivation for this research was again to underline the potential for airspace development but on a smaller scale with increased detail. Within Camden, Apex Airspace identified 475 potential sites for development which could equate to 2485 new homes and 28% of the boroughs current housing target. The report then extrapolates a housing density of 1.14 homes per Hectare to quantify a housing potential of 179,126 homes across Greater London (Ooshuizen *et al*., 2016).

MAX architects, who aimed to quantify the airspace potential within the Central Activity Zone (CAZ), firstly criticised the local authority's approach to housing targets. With just 16% of the CAZ providing 83% of the housing target, this report highlights the capacity of low impact airspace development to build in non-identified areas and increase housing provision. With a relatively small trial identification of 1km^2, a housing density of 7.95 homes per hectare was predicted and extrapolated out across the CAZ. The report concludes with commenting upon its likeness to the Knight Franks SKYWARD report, stating that whilst many of the input parameters were identical, the differentiation in scale limits the comparisons. With a smaller study area, MAX architects incorporated factors such as townscape and urban design, whilst SKYWARD took an automated geospatial approach which ultimately led to the disregard of these factors.

The quantification of airspace development potential provided by these three studies plays an important role in the surge in motivation for rooftop development within London. Furthermore, the transparent approach adopted by these large stakeholders, providing access to spatial and technical information does enhance the achievability of rooftop development. Crucial for consideration to the BrightNest project would be the comments by MAX architects about the impact of scale and the inevitable trade-off between a city-wide assessment and softer design centred considerations.

2.2.1 Modular Construction

A design concept central to airspace development is modular building. The use of prefabricated units which are built off-site and simply lifted into place on-site, such an approach minimises on-site labour which allows a faster and less impactful construction (Astel Modular, No Date). With further reaching benefits of improved cost efficiency and flexibility, many commentators state modular building as the future of the construction industry (Nathan, 2018). Furthermore, Zion Market Research estimate the expansion of the US modular market to increase by 57% by 2025, whilst an even greater boom is expected in China and India as the construction industry switches to modular approaches (Zion Market Research, 2019).

The earliest notable application of modular building was from British engineer Isambard Kingdom Brunel, whom in 1855 during the Crimean War built a modular prefabricated hospital on the banks of the Bosporus. The structure, reportedly capable of treating 1000 people simultaneously, was constructed in the UK and shipped as separate modules to Asia in order to improve the provision of treatment (Harrison, 1969). Since early examples, the modular approaches have shown successful application to a range of situations. From the creation of temporary buildings capable of relocation to meet unexpected office and education facility requirements (figure 2.1; Grand View Research, 2018), to bespoke prefabricated penthouse apartments which in many situations offer the only possible extension to a building (figure 2.2)

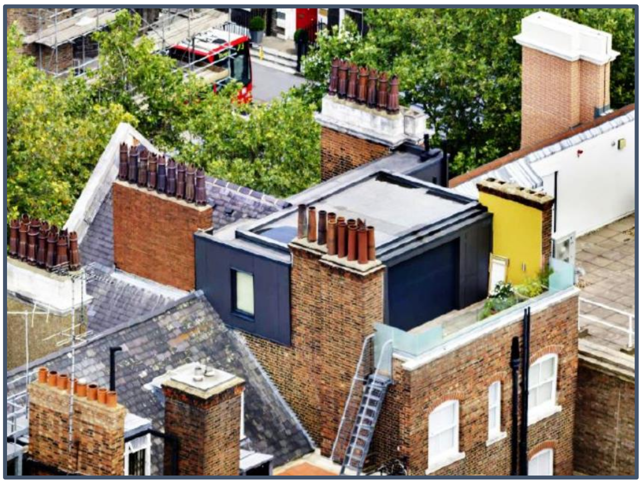

Figure 2.2: The rooftop airspace extension is again a prefabricated structure which was craned into position whilst access was constructed to provide a luxury living space in central London. (Modulek, 2014; Mara Build, 2010

Figure 2.2: Example of prefabricated relocatable module and rooftop airspace extension designs. The relocatable module are used as an education facility, whilst designed as a permanent structure, any requirement to move or deconstruct the structure can be done so with minimal effort and cost

The aspect of modular design most vital to the BrightNest project is the use of shipping containers within construction. Due to the inherent structural strength, low costs and widespread availability of containers there has been recent momentum towards their use as a core construction material (Radwan, 2015). Due to a containers weight bearing capabilities along with the durability of the steel frames, many containers can surpass 15 years of operation with minimal maintenance (Nunes, 2009) making them ideal structural components within larger buildings. From an architectural perspective, Radwan (2015) comments upon the designability of these modules, achieving a balance between spatial adaptability with the ease of modular construction. Yet the most central value to the use of shipping containers is that of sustainability. With an estimated 10 million shipping containers sitting on coastlines around the world (Boyd, 2013), extending their lifecycle through construction will avoid this storage issues and importantly reduce the amount wasted through the expensive and impactful process of smelting (Modis International, 2015). Furthermore, container structures are widely accepted to use significantly lesser embodied energy than traditional approaches to construction (Vijayalaxmi, 2010).

2.2.2 Parasitic Architecture

The architectural concept of parasitic architecture is a direct representation of that apparent in the natural world. A parasitic body is fed from the host to which it is attached and is therefore solely dependent on the host for survival, in construction this manifests as a structurally unique addition to a building or surface to which provides key infrastructure for the addition to function (Sensoy & Utsun, 2018). The benefits of this modern and abstract take on urban planning are centred on the creation of habitable space where it is perceived there is none and such approaches will be a key contributor to the provision of low cost, affordable urban housing (Kachri, 2009).

Figure 2.3: Example of parasitic architecture - the Rucksack House by Eberstadt (2004).

An example of such architecture is shown in figure 2.3, a structure named The Rucksack House. Located in Leipzig - Germany, constructed of wood and plexiglass and required only slight modifications to the host building to create access. Attached to the host building via only steel cabling, this was a very mobile design capable of relocation when required.

2.3 The use of GIS and RS in urban assessment

The second crucial aspect to the BrightNest project is the use of RS and GIS in urban planning and assessment. This very topical and active area of research holds a plethora of approaches and tools which could be implemented to the BrightNest project. This section will review those which are of most relevance to the BrightNest project and importantly those approaches which hold qualities of applicability and reproducibility. Focusing upon the use of LIDAR within urban environments and the approaches previously utilised for rooftop detection and site suitability analysis (SSA) within urban areas. GIS and RS are a fundamental pillar of each topic and will be present throughout this section of the review.

2.3.1 Remote Sensing in Urban Areas

With the advance of 3 technologies, capabilities and understanding, 3D modelling has become an ever more integrated into the planning and design of urban areas. Now an integral part of telecommunications planning (Knapp & Coors, 2008), solar radiation calculations (Palmer *et al*., 2018) and noise evaluation (Czerwinski *et al*., 2007), stakeholders require reliable and accessible data in order to conduct modelling. This data is most widely provided via the remote sensing methodologies of LIDAR and Photogrammetry. Whilst both methods ultimately produce 3-Dimensional modelling or landscapes (Solazzo *et al*., 2017), both do so via alternative methodologies and a subsequent trade off exists which influences their situational suitability.

LIDAR is an active system which creates dense 3D point clouds through the flight-time measurement of laser pulses. Whilst its conceptual knowledge was evident since the 1960s, the technology's potential was only understood with the advance of GPS systems in the mid-1980s. To date, LIDARs application potential has broadened due to the dramatic improvements in associated technology which allows LIDAR units to improve their power to size ratio. This has facilitated an improved accessibility for LIDAR units which can be used via Terrestrial Laser Scanners (TLS; eg. Rainato *et al*., 2013) or mounted upon Unmanned Aerial Vehicles (UAV; eg. Sankey *et al*., 2017). The benefits of this powerful system is the density of the generated point cloud created (Borcs *et al*., 2017); with point density as high as 150 Points Per Metre (PPM) from some airborne systems which allows for highly detailed 3D representations of an urban setting. Furthermore, LIDAR's mitigation of shadows, occlusions and poor contrast along with the high spatial density data is greater suited to the automation of analysis than ortho-imagery (Awrangjeb *et al*., 2013; Young, 2014).

However, whilst LIDAR facilitates this highly detailed 3D reconstruction, the enormity of gathered data is restrictive at larger spatial scales, requiring high computational power and many processing hours (Gopalakrishnan *et al.,* 2015). The greatest limiting consideration is however cost. LIDAR units are very expensive, when coupled with the cost of software and expertise such an approach would represent a significant investment for organisations to make (Saadaoui *et al*., 2019).

As aforementioned, LIDAR data can be collected through focused and detailed assessment of a building or geographic feature for example, yet many, often governmental agencies do provide extensive public domain LIDAR resources for better informed environmental decision making. In the UK this provider is the Environment Agency (EA), offering near complete coverage of UK territory between 0.25-2.00m spatial resolution (Environment Agency, 2019). However, the EA have to date only surveyed particular areas of interest to 0.25m resolution and the vast majority of the UK is only survey to 1m and 2m resolution. This data source presents itself as an invaluable tool for aspects of geoscience on the landscape level, as frequently utilised in flood zone mapping (Brown *et al*., 2016) or forestry (Hancock *et al*., 2017), it is also more applicable over city-scale due to the lower density of measurements.

Alternatively, photogrammetry is a passive approach which uses a series of overlapping ortho-photos to develop 3D geometrics of an object much like how the human visual system does (Hugenholtz *et al*., 2013). Requiring only a simple sensor system results in a photogrammetric approach having high levels of accessibility with straightforward integration with UAV systems, quite the opposite of heavy and expensive LIDAR units. Photogrammetry is most frequently represented in the literature by Structure from Motion (SfM) which has generated considerable interest throughout the geosciences (Ewertowski *et al*., 2019).

Photogrammetry, due to its simplicity sees a much greater application rate with a number of enterprises offering surveying and modelling capabilities. Examples of photogrammetric modelling include city-wide representations of Edinburgh (Vertex Modelling, 2013) and Basingstoke (TerraDrone, 2018). However, the most extensive photogrammetric dataset is provided by Ordnance Survey (OS) through its OS MasterMap Building Height Attribute. The OS product design team recognised a commercial desire for the rapid creation of products (Sargent *et al*., 2015) and produced a product which is today a fundamental aspect of urban modelling in the UK (Morton, 2013). The product contains relative and absolute height measurements in respect to ground level of the max roof height (AbsHMax / RelHmax) and a 'beginning of roof' measurement (AbsH2 / RelH2). However, as noted by Palmer *et al*., (2018), the lack of roof shape geometry in this data is major limitation to solar photovoltaic applications. OS has previously stated its intentions to expand and improve its Building Heights product (OS, 2014) and has subsequently reported success on roof shape recognition through the integration of Artificial Intelligence (OS, 2018). However, as of writing, this extension has not been made and the data is limited when projects require roof detailing, such as that of BrightNest.

2.3.2 Rooftop Detection

Expanding on the types of RS used within urban remote sensing, this section will review some of the methodologies deployed within rooftop detection, a vital step for the determination of suitable BrightNest sites. Rooftop detection is a very active body of literature, with authors building and adapting previous work (eg. Henn *et al*., 2013), however there is general acceptance of two groupings of approaches; model driven and data driven (Mass & Vosselman, 1999), groupings to which this section of the review will be organised. Furthermore, much of the literature called upon will be in relation to the planning and modelling of solar photo-voltaic (PV) energy. This application relates closely to the BrightNest project due to the basic site requirements of quantified roof angle and a minimum square area.

Data driven approaches, also known as the bottom-up or non-parametric approach, principally requires the construction and segmentation of planes from a data source such as LIDAR point cloud (Tarsha-Kurdi *et al*., 2007). Select methodologies and evaluations are discussed below but for greater detail and breadth on proven methodologies reviews by Henn *et al*., (2013) and Haala & Kada (2010) should be referred to. Whereas, model driven approaches often require a predefined model library, an algorithm will then iteratively attempt to classify each data feature to a specific library model (Tarsha-Kurdi *et al*., 2007).

Wang & Shan (2009) succinctly describe the further groupings of data driven methodologies. The authors state that 3D data driven modelling operates in the same manner; using part-time algorithm to extract simple building features. These extracted features are then classified and aligned to provide a finished model. However, employed algorithms can be further grouped into the structures they target; surface focused algorithms (targeting the roof form) and edge focused algorithms (targeting the boundary lines).

Regarding planar modelling, Random Sample Consensus (RANSAC), proposed by Fischler & Bolles (1981) – is an iterative best fitting of planar 'patches' is regarded as the most popular approach among users (Yi *et al.,* 2017). The model is favoured due to its simplicity in construction of primitive (uniform, regular) building features, allowing an automated and robust analysis. The RANSAC approach has notably been improved through the integration of Triangular Irrigated Networks (TIN; Chen *et al*., 2014) and octree structures (Vo *et al*., 2015) prior to modelling, the authors evidence these methods to significantly reduce the noise of the datasets and subsequent computation times. However, many authors report its failure to identify small scale planes (Yan *et al*., 2012; Xu *et al.,* 2016), particularly problematic on complex roof shapes. Alternative plane focused algorithms are commonly a derivative of region growing approaches. This technique employs seeds and growing criteria in order to correctly construct a plane's slope and elevation. It is viewed as easily operable and a basis of 3D modelling (Vo *et al*., 2015), however, under automation this technique has increased error when subject to poor seed points (Awwad *et al*., 2010) and planar surfaces of minimal distinction (ie. Shallow roofs; Sampath & Shan, 2010).

2.4 Site Suitability Analysis (SSA) Approaches

The final technical aspect relating to the BrightNest project is the integration of SSA processes. The overarching term of SSA is described by Mukhopadhaya (2016) as the understanding of a sites quality and the influencing factors for location of an activity. SSA studies are frequently integrated with Multi Criteria Decision Making (MCDM) which is a quantifiable tool to support final decision making through the analysis of alternatives. Although SSA is not strictly reliant on GIS, the ability to undertake MCDM through the layering capabilities of GIS results in the paralleled application of the two techniques (eg. Baseer *et al*., 2017; Merrouni *et al*., 2016). Furthermore, Al-Shalabi *et al*., (2006) states that traditional decision making processes are brought to a whole new level through systematic integration of spatial considerations facilitated by GIS.

A brief review of literature reveals the widespread appliance of SSA, from the management of ecotourism (Bunruamkaew & Murayam, 2011) to the planning of evacuation shelters (Kar & Hodgson, 2008). Yet, two applications of SSA which are frequently visited and of great relevance to the BrightNest project are urban planning and renewable energy. A number of approaches and associated techniques in relation to these applications will be drawn upon below.

The simplest form of SSA is that of exclusionary criteria mapping through a Boolean approach. The gathering of a range of criteria which iteratively assess a site on suitability / non-suitability, upon overlay of these numerous criteria the sites will be narrowed down to those suitable to each criterion. Whilst simple in computation and application, Palmer *et al*., (2019) comment that such an approach can result in a number of final sites of no differentiation and for some applications finer detail in outputs would be required.

The Analytical Hierarchy Process (AHP) is an integral part of any MCDM. With multiple input criteria it is inevitable that criterion importance and subsequent influence upon a final model will deviate Saaty (1980) developed the AHP as logical, structured framework which improves the understanding of complex decisions. Through pairwise comparisons of each parameter the user determines trade-offs, which ultimately determines a hierarchical structure of parameter importance, reported as a parameters 'weight' within a range of 0-1 and their sum equal to 1 (Malczewski, 1999). This process is illustrated through by Ammar *et al*., (2018), whom conducted a SSA for the construction of solar powered pumping stations. A pairwise AHP was conducted on 7 input parameters which expectedly weighted the solar energy potential of each site the highest whilst weighted the distance of the sites from roads as the lowest parameter. Foroughi & Rasol (2016) solved a multi-criteria problem through the use of the AHP for urban renovation within Iran. The authors used the proven AHP but further included expert opinion in order to generate parameter weightings, concluding that the condition of skeletal material of a building is the greatest influencer on renovation requirements. This added stage of expert opinion is less frequent within methodologies, however, when such an approach is applicable its inclusion improves the quality of the obtained decision solution (Aly & Vrana, 2008).

An additional concept widely applied to site suitability is that of fuzzy multi-criteria evaluation. An advancement on standalone AHP, Fuzzy AHP is introduced to mitigate the following downfalls of the AHP process, as outlined by (Kabin & Hasin, 2011). The authors state that AHP is most applicable to clear cut decision scenarios, where a single resolution is reached. For more complex MCDM with a number of potential resolutions, a fuzzy approach allows for discrimination between multiple potential resolutions. Kabin & Hasin (2011) further identify the fuzzy approach as improving the accuracy of criteria weighting. Therefore, a users decision to implement a fuzzy AHP approach instead of standard AHP is based upon the characteristics of MCDM outputs.

2.5 Where does this BrightNest SSA fit?

Evident through the literature review of the BrightNest SSA project is the breadth of the project; requiring knowledge from the technical aspects of remote sensing reconstruction of urban structures to the social requirements of urban housing. Many aspects of the BrightNest SSA; including - remote sensing identification of building planes, possible areas of rooftop construction, SSA and AHP, are all well understood and widely applied within the literature. Therefore, the studies individual elements will be drawn from pre-determined methodologies from a number of authors. However, the overall combination and application of these elements towards an SSA for airspace development is a novel approach. Whilst the adjacent field of GIS SSA for photovoltaic energy is extensive, it appears there has been limited extension of this interest into that of modular building. One plausible explanation of this trend could be the additional complexities within the housing sector (Zhang *et al*., 2013), making the application of GIS and RS technologies somewhat removed from the real-world resolutions to the problems.

However, what can be argued is the inevitable increase in interest due to the requirement for housing solutions. The interest and activity within the PV application is the result of momentum within renewable energy and, importantly, the realisation of commercial success from such investments. Authors now comment that this momentum is inevitably going to prevail within alternative housing solutions, which identifies this modular rooftop SSA as novel research into a vital application for future social wellbeing within the UK.

3 Methodology

The following section describes the methodology for the undertaken BrightNest SSA. This study proposed a two-phased approach (outlined below), this allowed a reduction from a city-wide computationally expensive study, to a significantly smaller 'rooftops of interest' scale. Such a step is necessary due to the noise and complexities of both OSBH and LIDAR data.

Phase One: Rooftop Identification – this initial stage of the SSA focused on the physical attributes of the rooftops within Brighton and Hove, with application of criteria resulting in the binary identification of sites which were / were not suitable for BrightNest development. The parameters investigated in Phase One are; rooftop square area and rooftop angle.

Phase Two: Rooftop Ranking – With the study now focused to rooftops capable of development, Phase Two required the ranking of these sites through Multi Criteria Decision Making (MCDM) techniques. Further aiding future development efforts through the identification of desirable sites and allowing an overall assessment of the development potential held within Brighton and Hove.

It must be stated that there is number of possible methodologies which could achieve a similar assessment of rooftop development potential, especially for Phase One with a magnitude of remote sensing techniques which could be integrated. However, the methodologies were selected with a key aspect of the research aims – a reproducible and user-friendly methodology. Due to this study including both well-developed and understood techniques as well as more novel aspects, its future application to further urban areas is highly reliant on an understandable and well described methodology.

3.1 Study Area

As aforementioned, the study site for the BrightNest Project will be the City of Brighton and Hove. The city was previously regarded as a number of smaller individual population centres surrounding Brighton. Yet, as of 1997 the area is now regarded as the unitary authority of Brighton and Hove, which includes a number of smaller satellite settlements. Figure 3.1. shows the predetermined study boundaries within Brighton; the limits extend latitudinally from Hove to Brighton Marina and longitudinally from Kings Road (seafront road) to the Whitehawk area. Due to the limited availability of LIDAR data within Brighton the study area is restricted to 3.6km^2 and does not allow a complete city-wide assessment of development potential. Assessment at this scale is however supported by Knight Frank (2017) and Apex Airspace Development (Ooshuizen *et al.*, 2016), whom produced comprehensive and successive studies at similar scales.

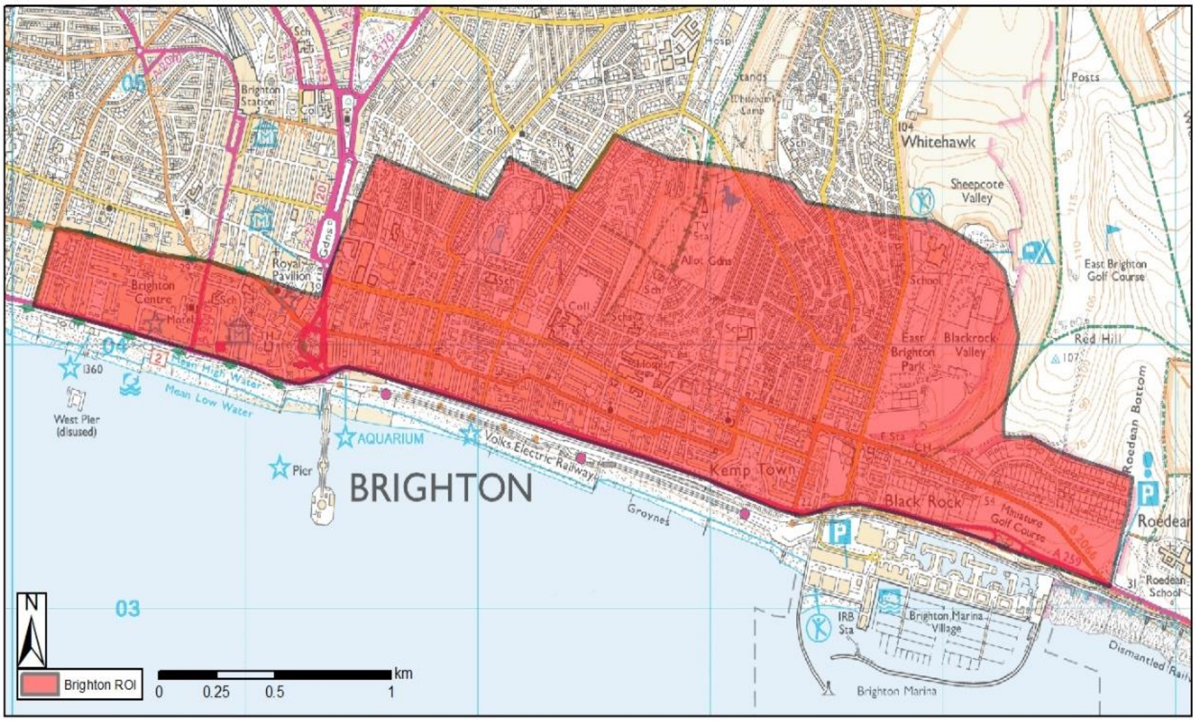

Figure 3.1: Brighton Region of Interest (ROI) shown in red, the area covers eastern parts of central Brighton.

3.2 Phase One – Rooftop Identification

3.2.1 The Data

Rooftop identification for the BrightNest study was undertaken using two public domain datasets. The first of which, Ordnance Survey's Building Heights data (OSBH), a frequent component of urban 3D modelling. A near national coverage, photogrammetrically derived data set, OSBH consists of 3 key building measurements; the buildings 2D plot, its ground to bottom of roof height and its max building height. Ordnance Survey collected this dataset through its own OS Flying Unit, high definition aerial imagery was collected over a number of years for processing at one of 30 photogrammetric workstations. The photogrammetry process involved the stereoscopic analysis of sequential images and image positions which allows the automated construction of a Digital Elevation Model (Ordnance Survey, No Date). Such measurements allow for the 3D reconstruction (as shown in figure 3.2) of all urban areas and is used extensively within both academic and commercial fields (The Economist, 2015). OSBH's successes lies within its simplicity; low computational complexity allows the modelling of extensive geographic areas and facilitates use by none expert users.

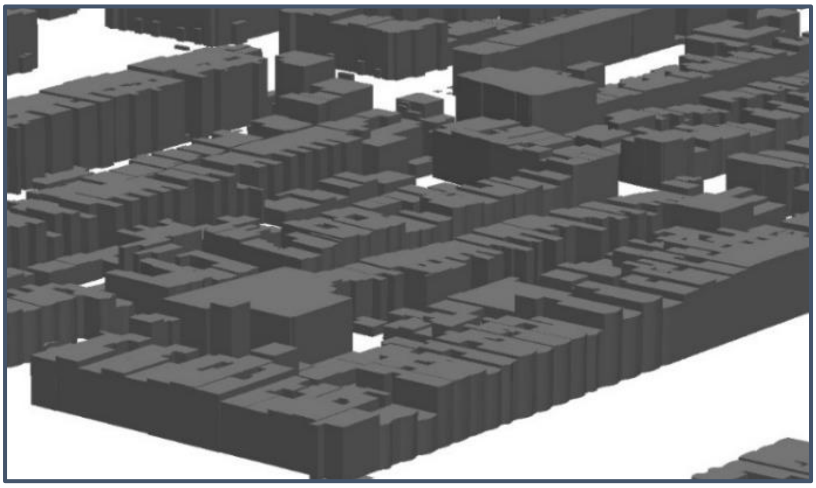

Figure 3.2: Example of an OSBH residential block in Brighton. The OSBH layer is displayed by an absolute maximum height reading (AbsMax2) with no exaggeration factor

Table 3.1: OSBH Brighton ROI Statistics

Polygons (Structures)	10,597
Roof Space (m^2)	847,852
Average Roof Size (m^2)	80.0
Max Height (m^2)	65.2
Average Height (m^2)	6.8

The data however does not provide rooftop detail. Whilst photogrammetry could facilitate the measurement of rooftops, Ordnance Survey do not include this within the product. Whilst no explanation is provided by Ordnance Survey for such a lack of detail, it could be assumed the complexities of such detail would present difficulties on such a large scale product. Ordnance Survey however are reportedly developing an Artificial Intelligence model fitting approach to address this issue (Walden, 2018). Subsequently 3D reconstruction via OSBH data only represents the 2D footprint of the building, eave beginning and max height and are represented as a flat plane.

The supplied OSBH data for the Brighton ROI is summated within table 3.1. Firstly evident is the flat plane representation of rooftops of an otherwise accurately modelled scene. Further observations can be made about the ROIs urban density, with 10,597 structures within a 3.6km^2 scene, the area is representative of the Victorian terraced design typical within Brighton. A final important observation is that average roof size, a relatively minute 80m^2.

Building on the detailed 2D plan information provided OSBH, roof modelling for the BrightNest SSA was facilitated through Environmental Agency (EA) LIDAR data. The EA have heavily invested in this resource over a number of years, with the aim of complete UK coverage to 1m resolution and certain ROIs surveyed to 0.25m, it represents a significant and important data product. Furthermore, the expensive and rapidly growing technology has important support from the development of low altitude remote sensing capabilities and is indisputable avenue for the future of 3D modelling (Cawood *et al*., 2017).

LIDAR operates through time of flight measurements of reflected laser pulses, systems are capable of making 150,000 measurements per second which allows for exceptionally detailed 3D reconstruction, often referred to as point clouds (example shown in figure 3.3). The EA state that 72% of the country has LIDAR coverage, unfortunately for this project this is not representative of Brighton. As shown in figure 3.4 LIDAR data coverage is limited to coastal areas with little coverage in urban areas. Explanations for this inconsistent coverage are likely the requirement for monitory of coastal processes, whilst inner city areas offer no project motivation. The coastal LIDAR coverage is however extensive enough for this SSA and the study area will form the boundary outlined in figure 3.1.

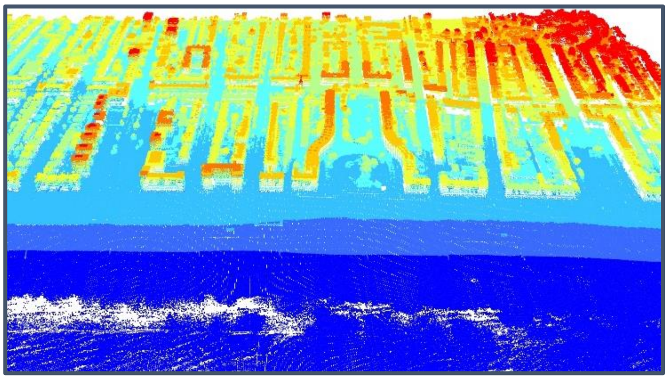

Figure 3.3: LIDAR modelling of Brighton from Offshore viewpoint. The increase in height from Sea to Beach to Urban structures is evident and importantly, the data models a structures rooftop.

Furthermore, LIDAR allows for a greater amount of discernible information from a scene due to its variability in detection. Data can be received as multiple partial return of a pulse, as experienced when sensing vegetation, which allows structural information to be gathered. A second important concept is that of ‘last return’, the final return of laser indicates an interaction with a solid object (tree trunk, ground or building), which provides differentiation between vegetation and buildings, for example (Wang *et al*., 2009). Alternatively, LIDAR can be measured in its full waveform, treating a pulse return as a continuous measurement which some argue produces greater accuracy in measurement (Anderson *et al*., 2015). The product is provided as pre-processed Digital Surface Models (DSM) from or a high resolution point cloud format to a Root Mean Square Error (RMSE) of +/-0.15m (GOV.UK, No date). With the Point Cloud data format allowing selection of last return points, it mitigates the impact of vegetation on rooftop assessment (Bellakaout *et al*., 2016). For this study the pre-supplied DSM was selected due to its lighter computation requirements over a large study area.

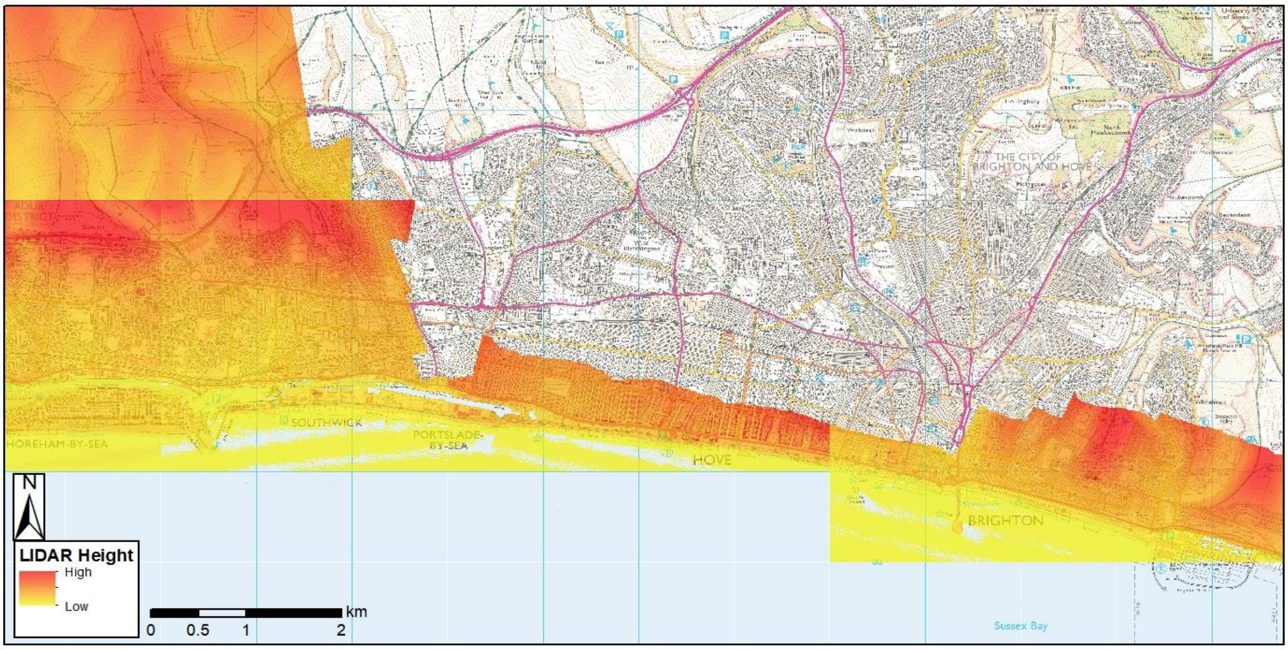

Figure 3.4: LIDAR coverage across OS squares TQ20 and TQ30, Shoreham to Brighton Marina

The literature has demonstrated that the OSBH and LIDAR resources will facilitate a structured and detailed analysis of Brighton's rooftops. These data sources also directly complement a key aspect of the research aims regarding the accessibility and reproducibility of the study. Utilising public domain data sets, without the incorporation of excessively complex data sources allows for this methodology's reproduction within other urban settings, a potentially vital concept of ongoing commercial development of the BrightNest project.

3.3 Phase One Processing

This following section describes the Phase One processing steps involving dataset modifications and the implementation of initial Roof Slope and Roof Area criteria.

3.3.1 Dataset Modifications

With the data amassed, initial modifications are required in order to filter extensive and computationally massive datasets. Firstly, the LIDAR DSM which covered 3.6km^2 was extracted to the footprints of the OSBH structures, reducing the size of the DSM to 0.84km^2. Essentially clipping the LIDAR DSM by the OSBH polygons allowed the reduction of a large DSM and focussed the study to Brighton's rooftops.

3.3.2 Roof Slope Filtering

The angle of a structures roof is arguably the most integral aspect to the SSA, as placement of a BrightNest module with minimal construction requirements is only possible on flat roofs. Therefore, the extracted LIDAR data for each OSBH footprint was transformed into an indication of slope. The ArcGIS function identifies the greatest change in gradient of the target cell from its 8 neighbours using Burrough and McDonnell's Average Maximum technique (1998). This layer was then subsequently queried for the desired "flat roof", which stated by the British Standard 6229 (BS6229) in construction as 0-10 Degrees (BMI Icopal, No Date). Whilst it is acknowledged that 10 Degrees is not a strict flat roof, this Standard acts as an important guiding value as the application of a 0 Degrees query would act as a significant constraint filter with very few sites likely to be brought through to Phase Two.

3.3.3 Roof Area Filtering

With sites of suitable slope identified, the next integral parameter for the study is the size of the flat rooftop identified. With BrightNest plans (shown in figure 1.1) detailing an internal floor space of 70m^2, this could be viewed as an absolute minimum possible for placement. However, with further considerations requiring additional roof space; an external terrace, utilities, access and construction, it was deemed necessary to increase the minimum required area to 100m^2. The spatial capabilities of ArcGIS 10.6. allowed the selection and removal of identified 'flat' roof cells below 100m^2, identifying final sites meeting the criteria of a flat roof and of minimum require size.

3.4 Phase Two – Site Ranking

The second stage of this BrightNest SSA relates to the development potential of each identified site. A structured Analytical Hierarchy Process (AHP) will be undertaken against 6 ranking criteria, quantification of the quality of the city's sites is a further indication of the commercial development potential held by Brighton & Hove. The following chapter states the motivation for each criteria's inclusion and describes the undertaken methodology for processing.

The criteria included within this SSA were identified through either specific BrightNest design implementations or through the assessment of relevant surrounding literature. Whilst a comprehensive assessment of all factors potentially impacting upon final development decision is beyond the scope of this study, the 6 criteria outlined below are those most critical towards the development at this early stage. The AHP Pairwise comparison process will assign weightings to each criterion relative to their importance to final site ranking. Criteria outputs were then reclassified into scores corresponding to a sites performance against each parameter, this is common approach with SSA

3.4.1 Solar Potential

Within the adoption of new Sustainable Development Goals across the United Nations is a target for a substantial increase in the share of renewable energy among the global energy mix by 2030 (United Nations, 2015). The markets for wind and solar photovoltaic energy have seen extensive growth in the last decade and are driving an unprecedented change in attitudes towards energy. In response to this global drive for change BrightNest and has designed the module to be fully self-sustaining through photovoltaic panels. The ability to achieve a self-sustaining module is therefore directly related to the solar exposure of the rooftop photovoltaic panels and consequently adds a significant constraint to rooftop placement.

The modelling of rooftop photovoltaic potential has seen extensive literature development which has subsequently seen the development of a range of modelling approaches. Some examples include Wiginton *et al.*, (2010) whom employed a true colour Object Based Image Analysis (OBIA) approach, achieving sub-pixel resolution to determine the available space for rooftop installation. Development has also been seen within the quantification of solar potential, Schallenberg-Rodríguez (2013) used urban statistical data within a solar model to calculate city-wide development potential. There has also been important development within the geostatistical platforms where solar modelling capabilities have been included within extensions. This is viewed as a vital development for the renewables industry with modelling capabilities becoming increasingly accessible for all stakeholders (Kazak & Swiader, 2018). GIS platforms have subsequently shown success within urban energy systems and urban development relationships assessments (Woch *et al*., 2017).

Assessment was made through ArcGIS's spatial analyst capabilities. This modelling is based on hemispherical viewshed algorithms developed by Rich *et al*., (1994) and Fu and Rich (2002). Calculation outputs are provided as global radiation, the sum of direct (unimpeded energy to the surface of the Earth) and diffuse (energy scattered by the Earth's atmosphere and received by the surface) radiation calculations, which are performed for each raster cell. However, the more complex parameter of reflected radiation from features on the surface is not included within modelling. The full solar radiation equation within the ArcMap spatial analyst extension is provided in Appendix 1.

The model calculates solar radiation units as Watt Hours per Square Meter (WH/m^2) across the selected days of Summer Solstice, Winter Solstice and Summer Equinox, providing an average of the extremes experienced throughout the year (Chow *et al*., 2014). The output DSM is for the entire Brighton scene and can then be extracted to provide solar radiation values for the sites identified through Phase One. Following similar methodologies employed by Berry *et al*., (2013), among others, this tools most crucial indication will be the impact of shading from surrounding urban structures, which allows the quantification shading has upon solar potential. An example of this analysis is provided in figure 3.5, one site is within the shadow of surrounding buildings whilst the other has no shading and a higher insolation across the assessment period.

For incorporation into the AHP these solar potential calculations required reclassification into a performance scoring system. The setting bins for the scoring system is described by Palmer *et al*., (2019) as a difficult decision within an SSA, due to the absence of guidance for photovoltaic thresholds within the UK and the global variability of solar levels rendering overseas thresholds incompatible (ESGP, 2014). In order to determine minimum solar thresholds, Palmer *et al*., (2019) and Merrouni *et al*., (2016) both refer to the Global Horizontal Irradiance (GHI); a national scale model which depicts the level of shortwave radiation received by a surface horizontal to the ground. The authors adopt a Boolean minimum threshold value of 210Wh/m^2 average hourly GHI (5040 Wh/m^2 Daily). Whilst this value is in line with that determined for the Brighton ROI of 5653 Wh/m^2, this criterion was to adopt a scoring system rather than a Boolean approach and therefore the scoring bins were set internally through the Standard Deviation of Solar irradiation. This is outlined in table 3.2 with 6 classes separated by 477 Wh/m^2 bins.

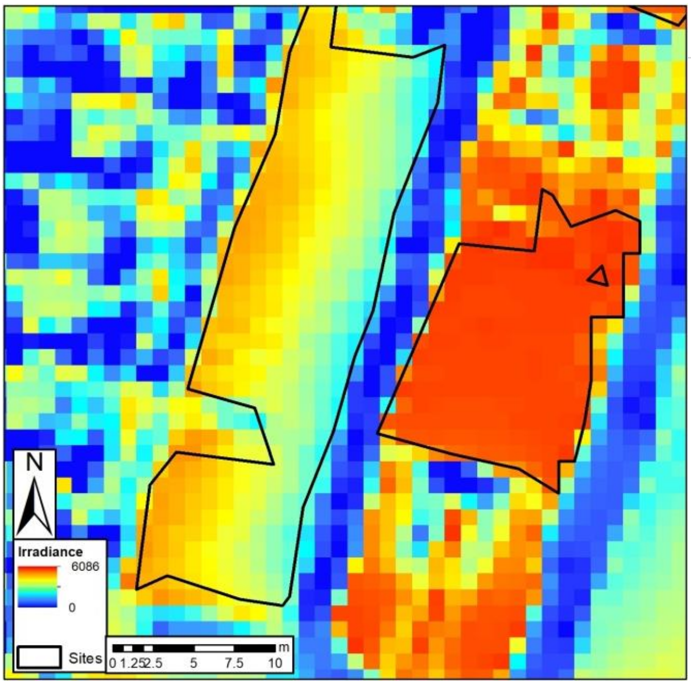

Figure 3.5: Shows an example of a high solar irradiance rooftop in dark shades of orange and a low solar irradiance rooftop. This is caused by the shade cast by the taller for large parts of the day.

Table 3.2: Scoring reclassification of rooftop solar potential

Score	WH/m^2
1 (Most favourable – 1StD Above)	5176 – 6130
2 (1StD Below)	4699 – 5175
3 (2StD Below)	4221 – 4698
4 (3StD Below)	3744 – 4220
5 (4StD Below)	3267 – 3743
6 (Least Favourable – 5StD Below)	2790 – 3266

3.4.2 Plot Size

Although BrightNest was designed as an environmentally focused single modular living space, commercial decisions are determined by practical implications. The ability to place multiple units within an identified site is commercially attractive due the benefit - cost ratio of constructing multiple units with one use of resources. Therefore, the sites will be assessed for the number of units capable of construction within a site, the parameters measured include square area and the geometry of the site.

3.4.3 Building Protection

Under the UK Planning (Listed Buildings and Conservation Act) 1990 strict protection is given to those buildings that hold special historic or cultural values. In practice this results in thorough investigation into any proposed changes or modifications, requiring detailed proposals by the developer. Structures are listed as Annex I – Buildings of exceptional interest, Annex II* – Particularly important buildings of more than special interest, Annex II – Buildings of special interest.

Therefore, identified sites located on protected buildings would be less attractive for development due to these added constraints and would require careful consideration of the wider benefits of the BrightNest project. The criteria will be assessed through the GIS information provide by Historic England, identifying each structure under protection along with its listed grading. Once again, the weighting of this criteria within the AHP was high due to construction restrictions on highly protected buildings.

Figure 3.6 displays Natural England's records for building protection within the scene. There are 473 listings in total, 9 Grade I, 20 Grade II* and 444 of Grade II. Evident is the spatial concentration to central and coastal area, with very few located away from coastal areas. Table 3.3 shows the approach to quantification taken for this layer, grading sites from 'most favourable' to 'least favourable'. Whilst this criterion could have been incorporated as a restriction layer in Phase One, efforts were made to modify the data from a binary (yes / no) to a discontinuous scale of impact severity to avoid a disproportionate impact on site identification.

Sites were assessed on both the degree of impact and the significance of the building. A sites degree of impact was determined by either a direct intersection with a protected building, or if it was within a 10m buffer of the building as exemplified in figure 3.7. This approach distinguishes between direct modification and constructional effects upon adjacent buildings, whilst the impacts of noise and vibration have a greater impact radius they were deemed beyond the scope of this study. The second aspect of building's significance was determined by its listing status (Grade I, II or II*), with higher protection indicating greater significance. The scoring reclassification is stated in table 3.3 with the least favourable sites having a direct impact upon a Grade I building.

Table 3.3: Scoring reclassification of building protection status

Score	Quantification
1 – Most Favourable	Not within 10m of a Listed Building
2 – Favourable	Within 10m of a Grade II Building
3 – Unfavourable	Direct Impacts on Grade II Building OR within 10m of Grade I or Grade II* Building
4 – Least Favourable	Direct impacts on Grade I or Grade II* building

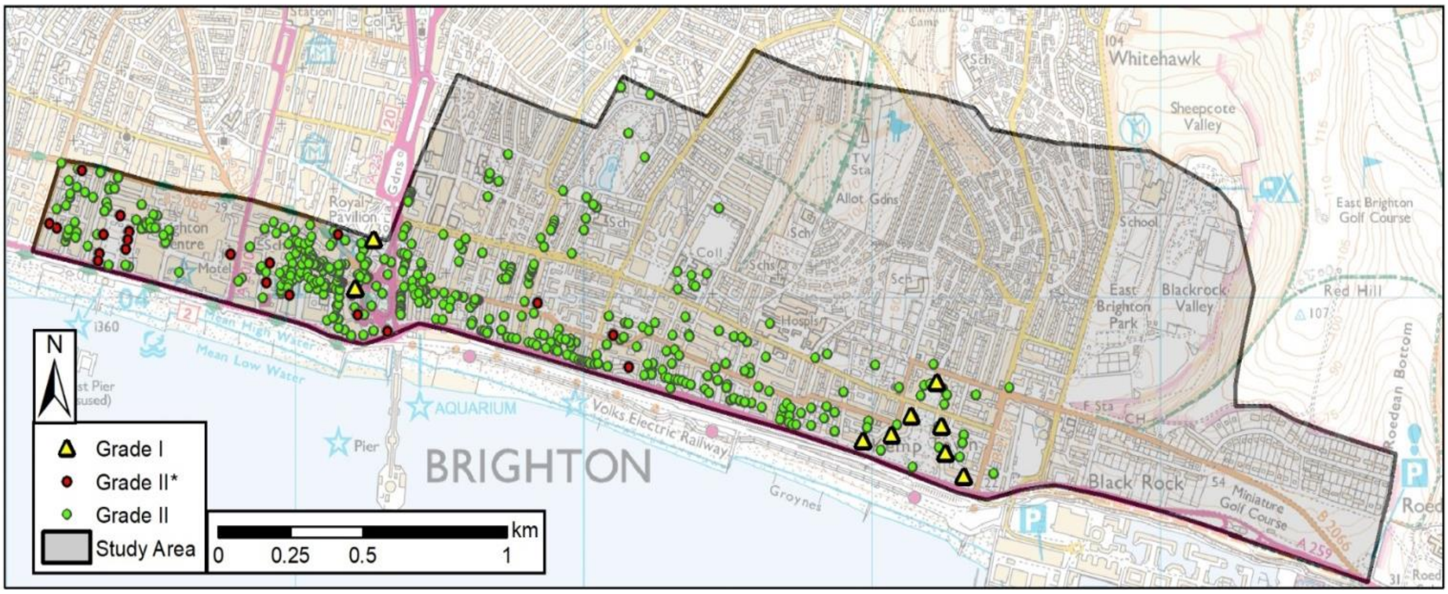

Figure 3.6: Protected buildings within the ROI - evident is a high concentration towards central and coastal areas.

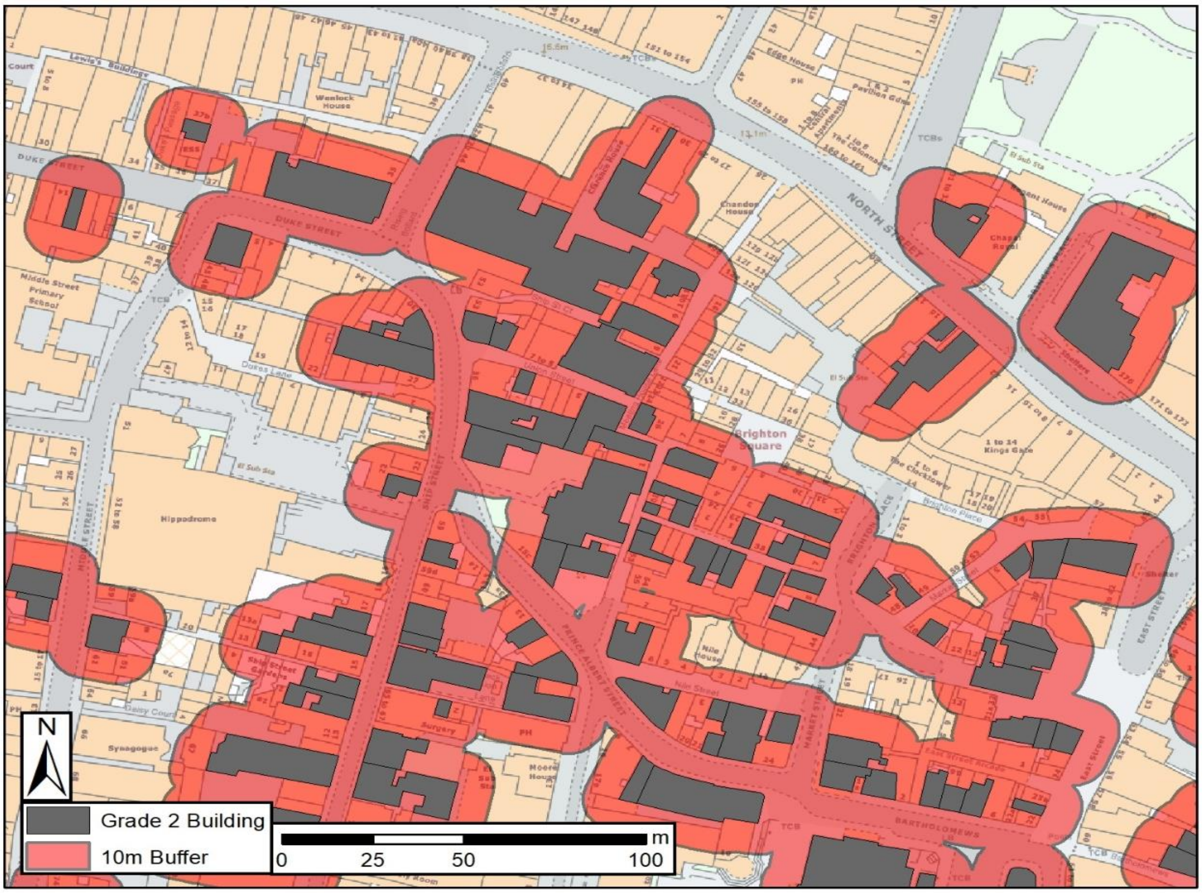

Figure 3.7: Buffer methodology employed for assessment of protection criteria

3.4.4 Roof Angle

Whilst the British Standards for construction flat rooves definition of 10 Degrees was utilised for Phase One site identification, a rooftop angle still has effects upon the construction processes and therefore requires consideration within Phase Two of the SSA. Guidance surrounding construction highlights the costs requirements of sloped surface construction and firms specialising in rooftop modular placement describe the rigorous process of flattening a rooftop for modular placement (eg. First Penthouse, 2019). Whilst the relationship between building costs and slope exist, guidance which could support the thresholding of a scoring system does not exist and therefore thresholding will be split into five 2 Degree bins from 0-10 Degrees, shown in table 3.4. This criterion was assessed through the slope layer constructed from the LIDAR DSM.

Table 3.4: Reclassification of roof angle

Score	Angle
1	0-2
2	2-4
3	4-6
4	6-8
5	8-10

3.4.5 Coastal Distance

A sites coastal distance is an important driver within the housing market, with Knight Frank (2014) stating that within an urban area a sea view adds a 47% premium to properties within the UK, it was an important inclusion for the BrightNest SSA. Assessment was made via ArcGIS's measurement capabilities using the OS Building Heights data with Digimap's vector backdrop mapping for identification of the seafront promenade. Scoring reclassification was once again implemented via distance buffers, the bins of which were advised by a similar study conducted by Conroy and Milosch whom identified the most suitable buffers for coastal distances upon the housing market to be 500ft (152m).

3.4.6 Green Spaces

A further important criterion within urban areas is access to green spaces. Green space is planned designed and managed to provide social, economic and environmental benefits (London Assembly, 2013), and has been strongly linked access to green space with benefits to both physical and mental health (Kondo, 2018). As a whole the UK is performing well to the 2014 policy paper “Improving Access to Green Spaces” with the average UK urban household being 258m from a functional green space of 2 hectares minimum size (Office for National Statistics, 2018), below the governmental recommendations of within a 300m radius (Parliamentary Office of Science & Technology, 2016). These green spaces are identified as vital features within an urban area which have widespread personal benefits and will therefore influence the suitability of a BrightNest site.

This criterion was assessed through data supplied within Ordnance Survey’s Mastermap, which depicts functional green spaces of at least 2 Hectares in size. As shown on figure 3.8, within the Brighton ROI there are only 3 functional green spaces; Kemptown Enclosures, The Royal Pavilion and Queens Park. Sites were assessed on Euclidian distance to the nearest green space through the creation of distance buffers. The ONS and “Improving Access to Green Spaces” policy paper advisors an individual should be within 200m of greenspace for maximum wellbeing, this therefore justified a scoring reclassification using 100m bins as appropriate the BrightNest site suitability analysis. 100m buffers were created and corresponding sites were assigned the scores outlined in table 3.5.

Table 3.5: Classification for distance to green spaces

Score	Distance Buffer / metres
1	Within 100m
2	Within 200m
3	Within 300m
4	Within 400m
5	Within 500m

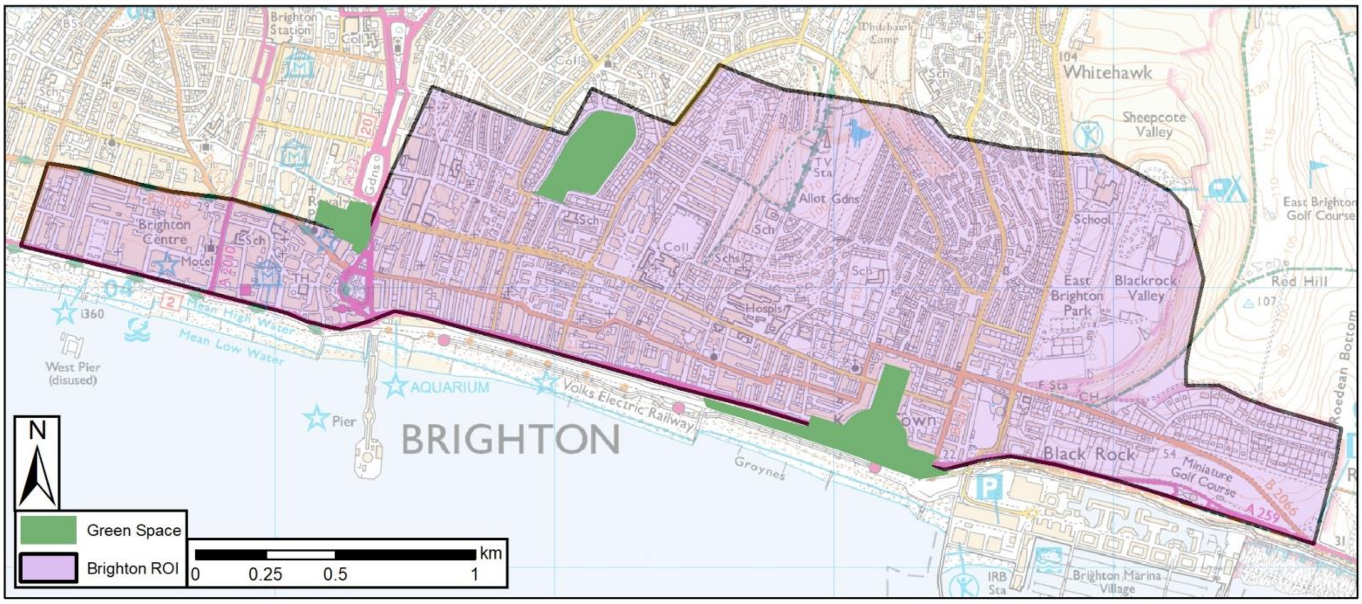

Figure 3.8: OS Mastermap’s functional Green Spaces – details three designated sites, Kemptown Enclosures, Queens Park and The Royal Pavilion.

their simultaneous integration into the BrightNest SSA. Saaty's (1980) AHP provides a framework for the structuring of a complex decision problem, allowing a user to express a weighting factor through the inclusion of pairwise comparisons (Xu & Liao, 2014). The result of the process is a MCDM problem where components have been dismantled in order to quantify their relative importance to the overarching objective and performance against alternative options. As shown in figure 3.9, the level 1 objective of the study is the BrightNest rooftop potential which is determined by the criteria and alternative decisions which could be made. In this study the AHP weightings were used to modify Phase One sites performance to each criterion.

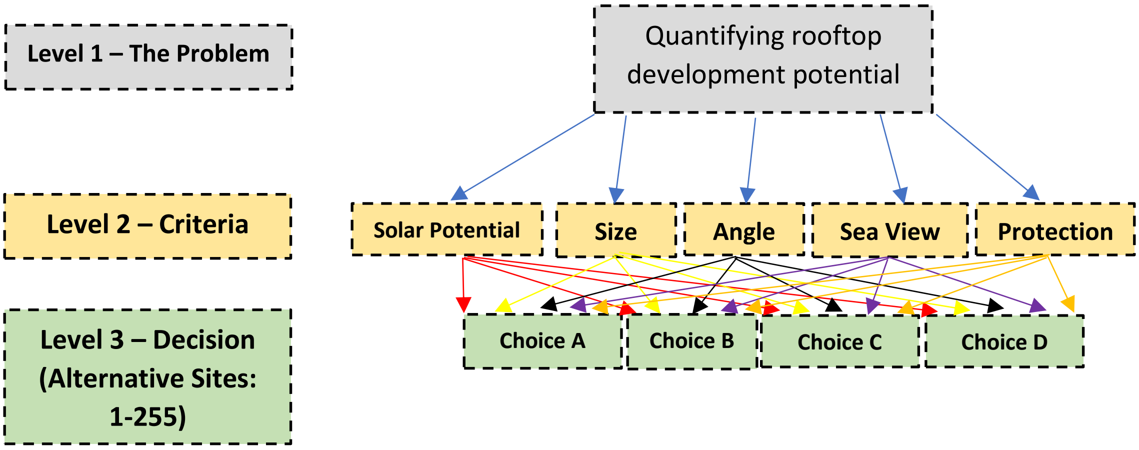

Figure 3.9: AHP Structure

3.5.1 Pairwise Comparison

The setting of the hierarchical structure is followed by a Pairwise Comparison to determine the importance of each criterion and attach an importance weighting. This stage reduces the complexity of multi-factor decisions to a series of one-on-one decisions furthermore it facilitates the integration of consistency controls through the Consistency Ratio (Saaty, 2012). Study designs most commonly involve the use of a panel of experts to participate in pairwise decisions (eg.); however, attaining an expert panel of sufficient size was deemed unfeasible for this study. Alternative approaches could integrate a decision-making software, authors Peng & Peng (2018) and Javadian *et al.*, (2011) showed successful application of 'SuperDecision' and 'USP-DSS' software to multi-level, complex problems. However, these decision support software programmes are subscription-based services and are not appropriate for the reproducibility aspect of the Study Aim 1. Instead, pairwise comparisons were informed through the recognised approach of a detailed assessment of relevant literature. Due to this approach being less specific to a problem than consultation with experts directly, its utilisation within the literature is significantly lesser than alternative methods. However, efforts were made to ensure selected literature was from the built environment and of identical structure to that employed in the BrightNest AHP. A record of consulted literature is shown in table 3.4, the relative rankings from 29 sources were transformed into a weighted value of 1 to determine the highest ranking criterion. The results of which are shown in table 3.5 – the literature identifies Area and Solar Potential as the two highest ranked criterions and building protection as the lowest at a weighted value of 0.11.

Table 3.4: Literature Assessment for Pairwise Comparison decisions

Criterion	Rankings
Slope	**6/10** (Gumasey 2016) | **5/14** (Li 2018) | **2/4** (Merrouni *et al.,* 2018) **8/9** (Xu et al 2011) | **14/19** (Çetinkaya, 2016) | **8/15** (Erbas *et al*, 2018) | **1/11** (Dong *et al.* 2008)
Area	**19/19** (Çetinkaya, 2016) | **3/7** (Foroughi & Rasol, 2016) | **6/7** (Degirmenci *et al*, 2018) | **8/10** (Sanchez-Lozano, 2013)
Protection	**2/14** Li (2018) | **5/8** (Hariz *et al*., 2017) | **2/5** (Du & Wang, 2018) | **3/8** (Pasalari *et al*., 2019) | **2/14** (Li *et al*., 2018) | **4/12** (Kara & Doratli., 2012)
Coastal Distance	**10/12** (Kabak M. *et al* 2018) | **1/5** (Du and Wang, 2018) | **1/9** (Shaghaghipour & Larijani, 2017) | **1/9** (Hoang, 2018) |
Solar Potential	**6/7** (Ammar, 2018) | **2/3** (Asakereh, 2017) | **6/7** (Georgiou & Skarlatos, 2016) | **8/8** (Merrouni *et al*, 2018)
Green Space Distance	**8/12** (Kabak *et al*., 2018) | **2/8** (Khatibi & Najafi, 2015) | **2/4** (Lotfi & Solaimani, 2009) | **8/14** (Errouhi *et al*., 2018)

The Pairwise Comparison Matrix for the BrightNest criteria was then conducted using the literature determined importance weightings as the studies expert opinion, these values were used to score each comparison (ie. Solar vs Slope, Slope vs Protection) a level of importance from Saaty's 1-9 scale (1977). Shown in table 3.5, the widely adopting scoring system involves assigning a value respective of the level of importance one criteria has over the other.

Table 3.5: Saaty's 1-9 Scoring System for Pairwise Comparison (1977)

Score	Reasoning
1	Equal Importance
3	Moderate Importance
5	Strong Importance
7	Very Strong Importance
9	Extreme Importance

Each Saaty comparison score is input into the top half of the exemplified matrix in table 3.6. With duplicate criteria scoring a 1 (Equal Importance) across the central line, the bottom half of the matrix was calculated by taking the reciprocal function of the top half to generate the opposing score of identical significance. The Saaty comparison scores then required normalising through the sum of each column to produce associated eigenvectors and finally principle eigenvectors through averaging across each row. This principle eigenvector is a weighted value from 0-1 and portrays the criterion importance that each site was assessed upon.

The developed eigenvectors are then subject to a consistency controls to determine the quality of application of Saaty's 1-9 comparison score. The process to develop a Consistency Ratio is outlined below (figure 3.10):

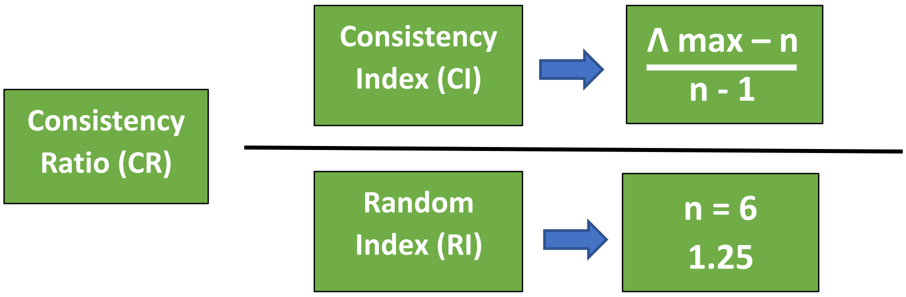

Figure 3.10: Consistency Ratio Calculation

The CI is calculated through determining the average matrix product from each eigenvector and the corresponding Saaty comparison score, in practice, this involves multiplying corresponding matrix rows from the Saaty comparison score and the normalised eigenvector matrix. This average CI value is then divided by the Random Index (RI; Saaty, 1980), a pre-determined value for mitigating variation, to determine the Consistency Ratio (CR). The literature states a consistency ratio < 0.10 indicates consistent decision making throughout the AHP.

The final stage is to integrate the results of the AHP into the GIS modelling, adjusting each sites criteria performance to the relevant weight and therefore producing a final site suitability score.

Table 3.6: Pairwise Comparison Matrix Example

	Slope	Size	Solar	Seafront	Protection	Green Space
Slope	**1.00**	🟦	🟦	🟦	🟦	🟦
Size	🟧	**1.00**	🟦	🟦	🟦	🟦
Solar	🟧	🟧	**1.00**	🟦	🟦	🟦
Seafront	🟧	🟧	🟧	**1.00**	🟦	🟦
Protection	🟧	🟧	🟧	🟧	**1.00**	🟦
Green Space	🟧	🟧	🟧	🟧	🟧	**1.00**

3.6 Validation

The methodologies employed for site identification and ranking were then subject to validation in order to further highlight discrepancies and certify correct results. For Phase One – discrepancies were identified through an initial review of modelling outputs, these were then subject to a user visual assessment against Google Earth aerial imagery to identify their impact upon the site.

Phase Two validation employed the One At a Time Sensitivity Analysis (OAT-SA) approach – an iterative process adopted by authors to emphasise uncertainties within the data. Whilst Sensitivity Analysis can be achieved through regression, correlation (Manache & Melching, 2008) as well as the popular Monte Carlo simulation (Hornberger & Spear, 1981), OAT-SA was selected due to its favourability to spatially centred studies. Chen *et al*., (2013) and Feick & Hall (2014) both demonstrate this through displaying the change in suitability maps through successive iterations of analysis, an approach well suited to this BrightNest analysis.

The OAT-SA approach is used to adjust the weightings of each criterion individually (or One At a Time), this allows insights on the impact each criterion has upon final site performance. In this instance, the weightings of one criterion was raised by 1% whilst the other five were lowered by 1%, a process repeated at a higher magnitude of 5%. Through these adjustments, insights will be provided into the impact each criterion has upon site ranking within Brighton and how minute changes could affect the projects potential.

4 Results

This section is again reported in the two separate phases of the SSA; Phase One - identifying the possible sites within Brighton before Phase Two ranking the sites on pre-determined criteria. The outputs from this chapter will quantify the commercial development of the BrightNest project within Brighton and begin to assess potential for the further application of this methodology.

4.1 Phase One – Site Identification

Interrogation of the LIDAR DSM with the sequential constraints of a rooftop slope angle less than 10 Degrees and a minimum site size of 100m^2 identified 255 sites where construction of the BrightNest modules would be possible. Across the Brighton ROI there was 81532m^2 where BrightNest construction is feasible, constituting 9.3% of total rooftop area. Identified sites appear form clusters across the study area, with defined regions of the city holding a high density of sites with larger expanses having a more sporadic identification of sites. Four apparent clusters have been identified across the study area (figure 4.1), with no apparent pattern between the remaining sites. These hotspot sites are now investigated in greater detail in the following commentary.

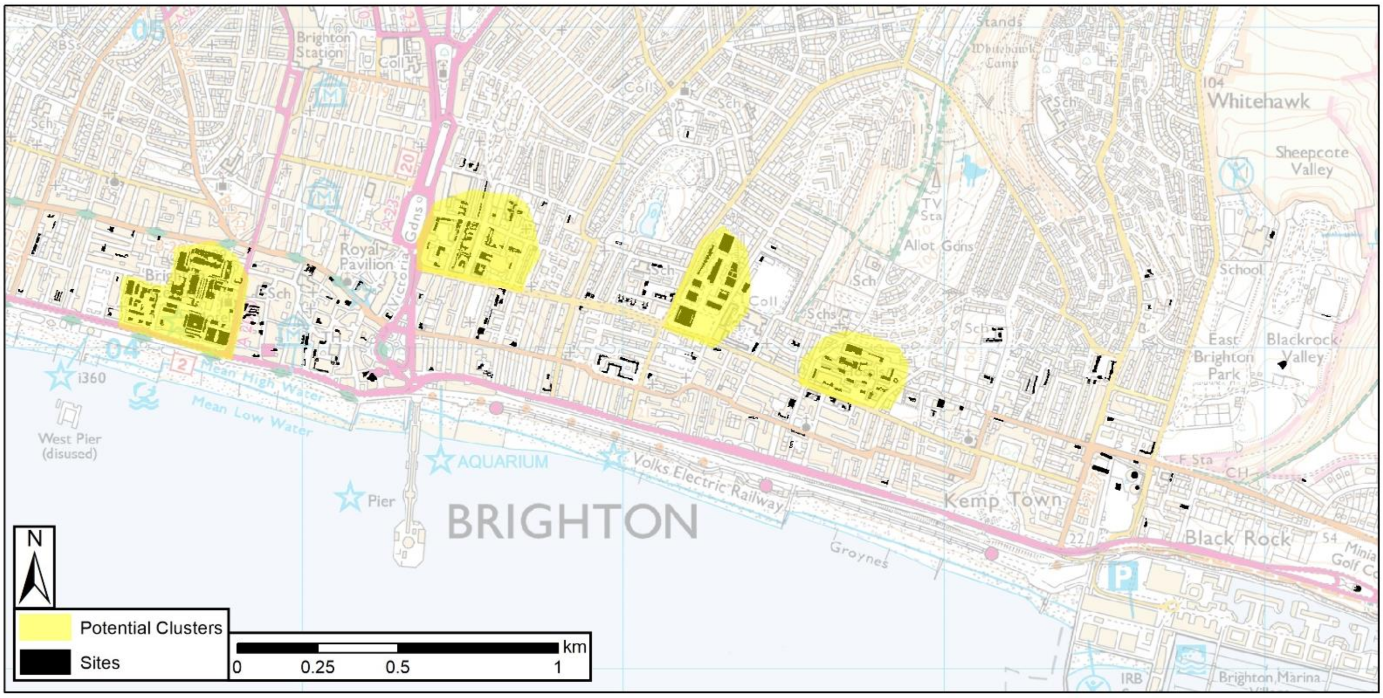

Figure 4.1: Potential clusters within Phase One Site Identification

The following mapping (figures 4.2. A-D) identifies ROIs with a high concentration of BrightNest site availability and show promising physical characteristics.

Figure 4.2A shows Churchill Square shopping centre; as typical with shopping centres it is a largely flat roofed structure. Within this scene there is 20019m^2 of development potential and therefore constitutes one of the larger sites within the Brighton ROI. Furthermore, the structures average height are 13m making it suitable for a BrightNest module to be hoisted into position. This site however does appear impacted by the presence of rooftop utility units (Air Extraction, Communications), an issue that requires further focus.

Figure 4.2B ROI indicates a significant site availability within the complex of Sussex County Hospital of 5531m^2; there are however a number of practical considerations which could reduce the favourability of the ROI. Firstly, the service of the buildings would pose significant development constraints, limiting potential sites. Secondly is the physical factors with some buildings in the complex exceeding 25m in height which introduces practical complexities with module hoisting. Finally, sites to the NE of the complex hold geometries which again would introduce complexities with module placement.

Figure 4.2C is a retail complex within the Kemptown area of Brighton. The site is characterised by a number of 1 and 2 story warehouse within the food and fashion markets. Holding a high square area of 2698m^2 and an average height if 7m, these sites appear favourable to development, yet complexities may exist through the structural details of these warehouse units.

Figure 4.2D is characterised by Victorian era buildings by the Old Steine, the sites are located on multi-purpose buildings, notable uses include Brighton Magistrates Court and Brighton Police Station and have total square area of 6856m^2. These sites are again of a feasible elevation at 12m^2 but are of greater complexity due to variable roof heights when compared to the retail complex identified in figure 4.2C, which could lead to further construction complexities.

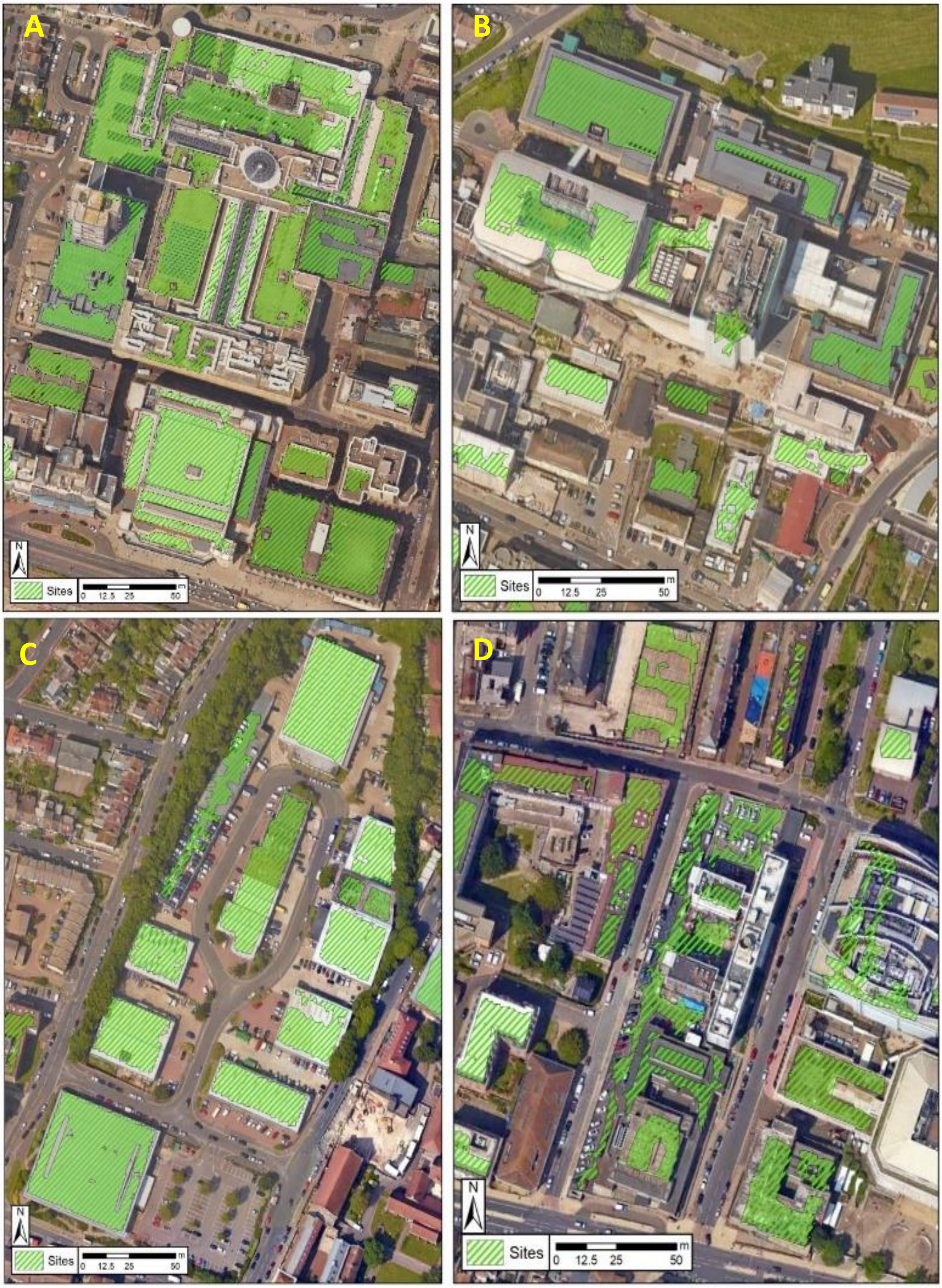

Figure 4.2 A-D: Example ROIs from which are of less than 10 Degrees slope and greater than 100m^2.

4.2 Phase Two – Site Ranking Results

With Phase One Site Identification completed, this chapter will present the results of the implemented AHP and integration into the GIS in order to quantify the potential for BrightNest development within Brighton.

4.2.1 AHP Results

The 29 literature sources presented in table 3.4 were used to determine literature criterion importance shown in table 4.1. This methodology, effectively acting as BrightNest's expert opinion, determined that across the literature Solar Potential is the most highly regarded criterion at a weighting of 0.22. This was followed by Site Area at 0.22, whilst site slope (0.15), distance to green space (0.14), distance to the coast (0.13) and site protection (0.11) were determined to have a significantly lower weighting. It must further be noted the lack differentiation between the bottom 4 criterion, which could have an important bearing on final site selection.

Table 4.1: Literature Criterion Importance

Criterion	Weighting
Slope	0.15
Area	0.22
Protection	0.11
Coastal Distance	0.13
Solar Potential	0.24
Green Space Distance	0.14

The literature criterion importance values from table 4.1 were then used as the studies expert opinion to inform the pairwise comparison matrix in table 4.2. These were subsequently normalised into eigenvector values in table 4.3 which act as the final weighting to be integrated into the GIS. The developed weighting identified Solar Potential and Site Area to again be the factors of greatest weighting, but with a summated value of 0.74, there importance were markedly increased through the decisions made within the Pairwise Comparison Index. Consequently, the weightings for final 4 criteria fell to values below 0.10 with little differentiation between the criteria.

The produced CR of 0.097 calculated from the priority eigenvectors was less than the critical limit of 0.10 recognised throughout the literature. This output indicates that the literature influenced pairwise comparison scoring was consistent and viable throughout table 4.2 and outputs can be relied on for further analysis.

Table 4.2: Pairwise Comparison Matrix (W values)

	Slope	Size	Solar	Seafront	Protection	Green Space
Slope	1.00	0.14	0.14	3.00	5.00	1.00
Size	7.00	1.00	0.33	7.00	7.00	7.00
Solar	7.00	3.00	1.00	7.00	9.00	7.00
Seafront	0.33	0.14	0.14	1.00	3.00	0.33
Protection	0.20	0.14	0.11	0.33	1.00	0.20
Green Space	1.00	0.14	0.14	3.00	5.00	1.00
Sum	16.53	4.57	1.87	21.33	30.00	16.53

Table 4.3: Normalised eigenvectors (E)

	Slope	Size	Solar	Seafront	Protection	Green Space	Priority eigenvectors	Consistency
Slope	0.06	0.03	0.07	0.14	0.17	0.06	0.09	6.37
Size	0.42	0.22	0.18	0.33	0.23	0.42	0.30	7.42
Solar	0.42	0.66	0.53	0.33	0.30	0.42	0.44	7.17
Seafront	0.02	0.03	0.08	0.05	0.10	0.02	0.05	6.04
Protection	0.01	0.03	0.06	0.02	0.03	0.01	0.03	6.29
Green Space	0.06	0.03	0.08	0.14	0.17	0.06	0.09	6.37
								Λ = 6.61
								CI = 0.122
								RI = 1.25
								CR = 0.097

4.2.2 Phase One and Phase Two Integration

With BrightNest sites identified and the final weightings for input criteria determined this section presents the combination of these two aspects and the final BrightNest sites. A general description of the overall dataset is presented in figure 4.3 and table 4.4 were the results are classified into suitability groupings in order to aid further analysis.

The overall performance of identified sites against the selection criteria was highly varied with weighted scores ranging from 1.66 to 5.58. The distribution of rankings was positively skewed with a mean score of 4.07 as sites generally performed well against the selected criteria. An important feature within the results is a high frequency of highly scoring sites with 11 sites scoring between 5.88 and 5.43. This could indicate there is an upper limit within the methodology which reduces the differentiation between these highest scoring sites.

This study proposes the results are classified into suitability groupings through the Standard Deviation of the 255 site rankings of 0.67. Classification of the results into 6 suitability bins revealed that 87.5% of sites fall within grouping 4 and 5, with 8 sites falling under the highest suitability grouping 5 sites under the lowest. Whilst the high number of sites falling under just two groups could be viewed as offering little differentiation between identified sites it effectively identifies a small number of sites most and least favourable for BrightNest construction.

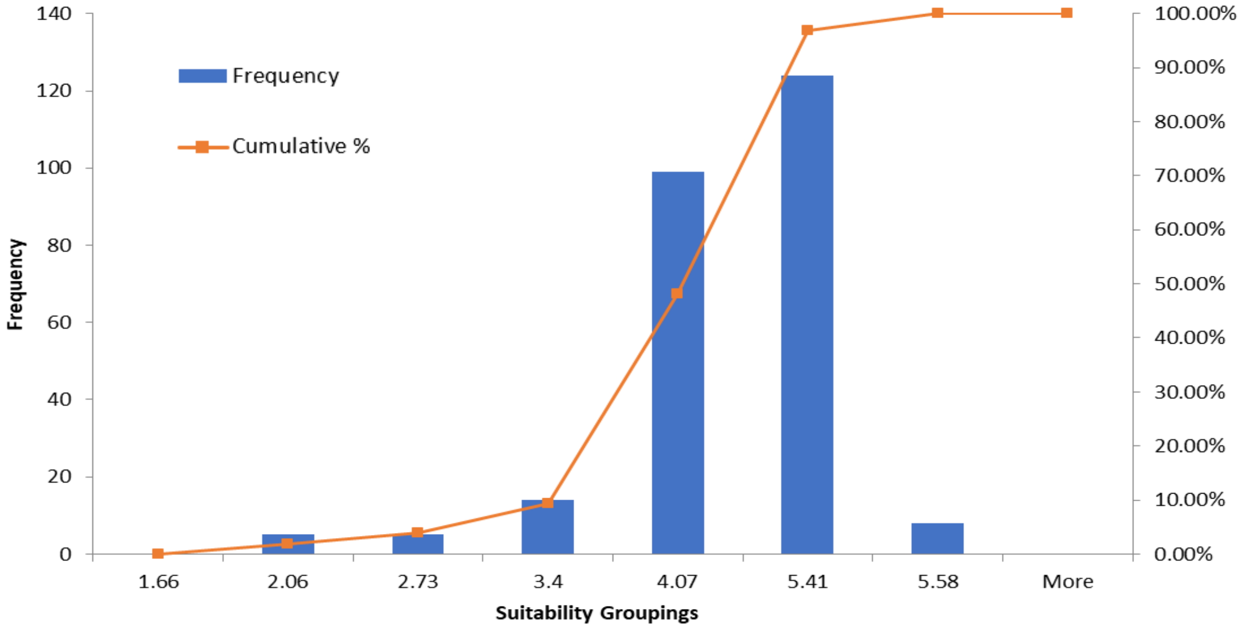

Figure 4.3: Histogram of Site ranking

Table 4.4: Suitability Grouping Statistics

Suitability Group	***Bin***	***Frequency***	***Cumulative %***
1	2.06	5	1.96%
2	2.73	5	3.92%
3	3.4	14	9.41%
4	4.07	99	48.24%
5	5.41	124	96.86%
6	5.58	8	100.00%
	More	0	100.00%
N =255	**StD = 0.67**		**X= 4.07**

Figure 4.4. displays the 10 sites of the highest and lowest performing overall weighted score. The majority of highest scoring sites are found around the Churchill square area and are located on the large sites of the retail shopping centre and large hotels on the sea front. A further high scoring site is located on the large warehouse structures within Kemptown retail park. Observations of the lowest ranking sites firstly reveals their considerably smaller size and locality on much small buildings of residential use. Further apparent is the non-uniform geometry with sites being typically narrow across and angular, a characteristic likely to be problematic for a rigid modular design.

At this stage high level judgements upon the characteristics of individual sites can be made which can focus further analysis into the relative failings and successes of the methodology. The following trends and discrepancies are discernible from insets A-G in figure 4.4:

- Apparent ‘Zig-Zag’ edges of site polygons - present on all sites to varying degrees, this characteristic has impacts upon available site area which impacts initial site identification and performance under the ‘size’ criterion.
- Impact of rooftop superstructures - insets A, B and D display sites which are interrupted by unavailable areas which are often central to the polygon and could subsequently interrupt BrightNest construction
- Rooftop angle - due to the complexity of many polygons displayed it is likely the modelling is occurring on complex rooftops. Whilst stated as a flat roof these polygons could be misleading to of the rooftop’s true geometry.

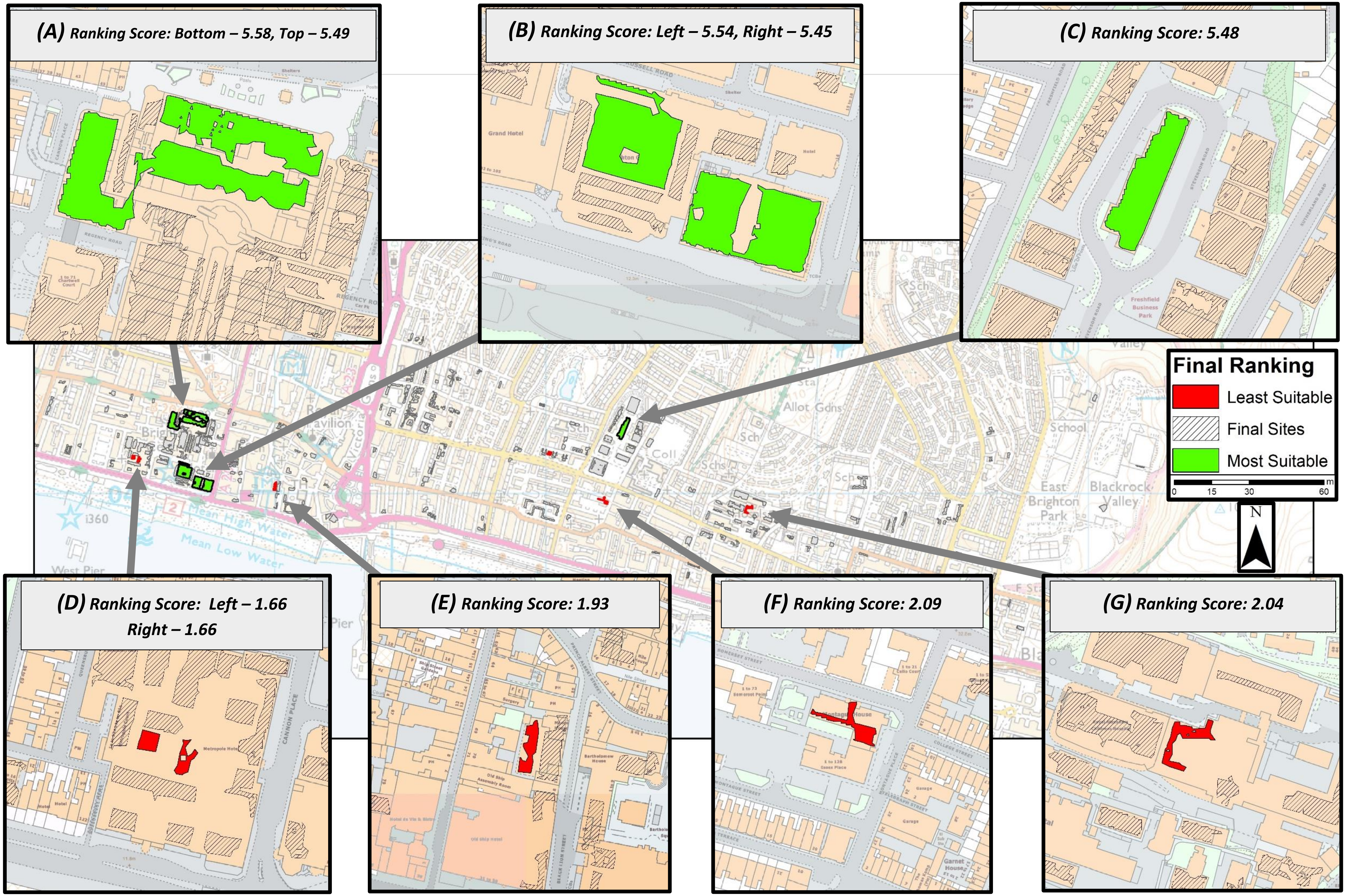

Figure 4.4: Final site rankings - 5 most suitable and least suitable are identified.

5 Analysis / Discussion

This BrightNest Site Suitability Analysis has identified rooftop sites which hold the physical characteristics for BrightNest development and has subsequently applied a ranking methodology to these sites in order to determine the desirability of each site. The ranked outputs therefore act as an assessment of the City's rooftop development capabilities for the BrightNest project and is progress towards the studies first research aim – Quantify Brighton's rooftop development potential and support its further commercial development. Through generation of these BrightNest outputs the study has also shown successes towards the second winder reaching research aim which focuses on the application of well-developed GIS SSA methodologies to airspace development opportunities. However, the apparent successes in relation to these goals require further investigation to determine their legitimacy and further support the second research aim of this study.

Through the incorporation of technical literature within remote sensing and GIS this section will investigate previously identified trends and discrepancies, allowing commentary to made upon the validity of modelling and the required improvements. The technical aspects of this chapter will however be accompanied by thoughts upon the practical implementation of BrightNest development and its impact on the wider SSA literature.

The chapter's structure is outlined below:

- Spatial analysis of site locations – the impacts of urban characteristics and the wider implications for BrightNest development;
- Phase One Remote Sensing validation – assessment of methodology employed for site identification;
- Phase Two Sensitivity Analysis – Assessing the stability of input criteria and the relationship between modelling inputs and outputs.

5.1 Cluster Analysis

As identified in the high-level assessment of the Phase One site locations there is an apparent clustering of the sites within the Brighton study area. The implications of this trend being confirmed are significant for both the future development of the BrightNest project and airspace development in general as it implies the characteristics of the urban environment have a significant influence on site locations.

This observation was assessed graphically through ArcMap's Kernel Density function and confirmed through Average Nearest Neighbours spatial statistics tool. Silverman's Rule of Thumb (Silverman, 1986) which is largely robust to the spatial outliers within the identified sites, was used to calculate the input Bandwidth of 324m. Evident within figure 5.1 is that the 4 potential clusters identified in initial assessments are also present through Kernel Density construction with a further minor cluster also developing to the East by Brighton Marina. The largest of which is the Churchill Square ROI which holds the highest density values in the study area. These patterns are confirmed statistically with Average Nearest Neighbours testing reporting a ratio of 0.689 ($X < 1$ = Clustered, $X > 1$= Dispersed) with a significant P Value of 0.000*.

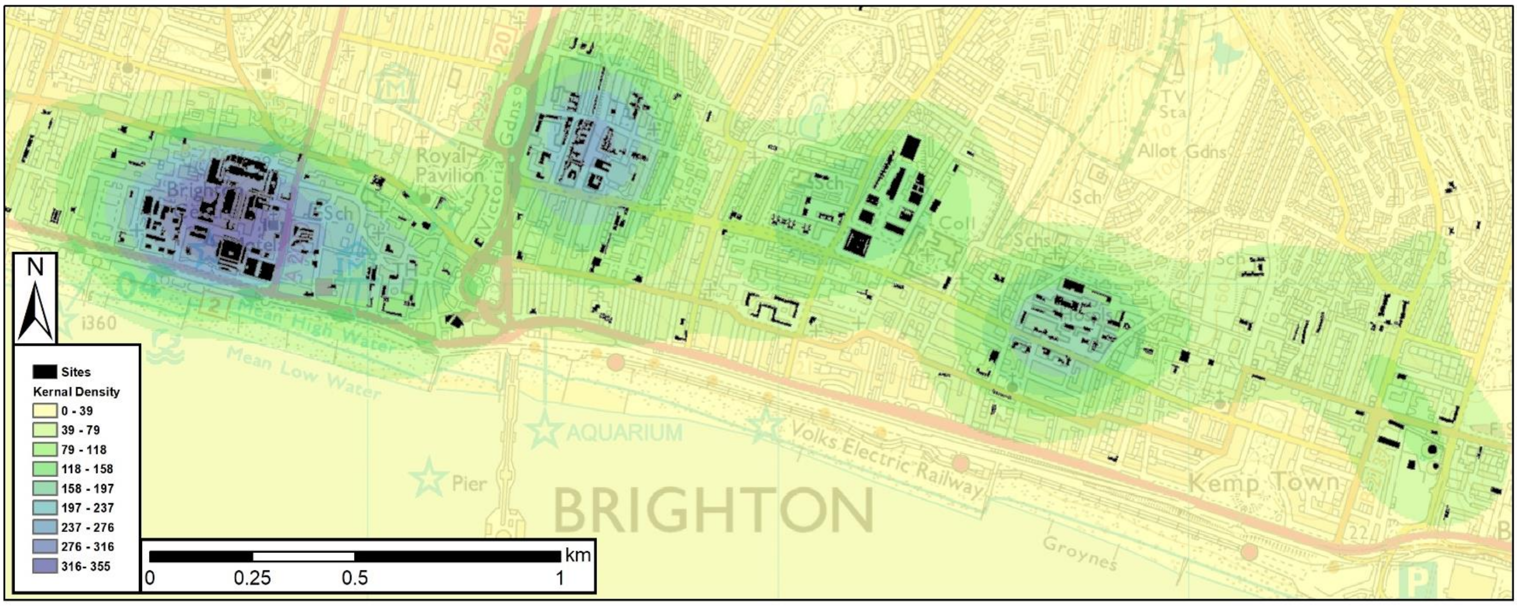

Figure 5.1: Kernel Density mapping reveals 4 defined clusters

The confirmation of these clustering patterns is an interesting and important output from this research as it indicates site identification is driven by the urban characteristics of Brighton. These clusters can then be described by their building typology, a term within urban planning used to describe structures of similar nature (Ballarini *et al.*, 2017).

There are two typologies present which represent 3 of the clusters; Campus Development (Royal Sussex County Hospital, Churchill Square Shopping Centre) – buildings of large footprints which make a good use of site space and Big Box (Kemptown retail park) – single-story warehouse style buildings accompanied by car parking for retail purposes. These Campus and Big Box sites hold a high density of sites which also score highly within Phase Two of the methodology, Furthermore, assessment of further typologies such as mixed-use outlier and residential streets show few identified sites, assumptions can therefore be made on the impact of building typology upon site identification and quality.

With the identified typologies holding 34.5% of the total sites the large plots and flatter rooves offered have a greater suitability to the BrightNest project than residential areas often characterised by smaller, angular rooves. Confirmation of this trend can therefore have important bearings on future revisions of the BrightNest model and the overarching target population of the project. Whilst the urban centre has a high provision of sites such a location will not be suitable for a proportion of the target market. Croydon Council (2010) identify that families often desire characteristics such as outdoor space, friendly neighbourhoods and direct access, characteristics which are hard to provide in built up urban areas. Therefore, the identification of this pattern further informs both the project and potential developers of the spatial induced constraints on the project.

5.2 Site Identification Errors

The implementation of a practical but computationally simple process of querying slope and rooftop size has the potential to produce errors that would not be present through a more expansive, refined site identification methodology. The characteristic errors identified through the brief review conducted in Chapter 4 were assessed in greater detail through a user visual assessment against aerial imagery. In this assessment, the user was to classify the impact each error has upon the viability of the physical parameters of the site, subsequently grading them as High, Medium and Low Impact. For the roof slope however, sites were assessed for High, Medium and Low Certainty of a flat roof. This assessment naturally led to the assessment of further methodologies which could mitigate the impact of these sites and the overall impact this has upon BrightNest development.

5.2.1 Aerial Assessment Results

Results of validation through aerial imagery assessment are summated in table 5.1. This step identified that rooftop superstructures have the greatest impact upon the physical suitability of a site with 31.4% of the sample group being highly impacted by a rooftop superstructure. The impact of the 'Zigzag' effect is consistent but to a lesser severity than rooftop superstructures and there were only two cases were aerial imagery indicated a rooftop was wrongly classified as a flat rooftop (<10%).

Table 5.1: Phase One Aerial Assessment

Impact (Certainty)	**Rooftop Superstructures** (%)	**Zigzag** (%)	**Flat Roof** (%)
Low	50.2	57.1	6.6
Medium	17.3	34.2	14.3
High	31.4	8.6	77.1

5.2.2 Rooftop Superstructures

Rooftop superstructures such as utilities, access routes and aerials are all capable of detection by high resolution LIDAR data. These features are pronounced from a rooftop surface and their detection was determined to impact upon almost half of validation sites. However, in practice many of these features can be easily relocated for the accommodation of a BrightNest module and their detection therefore acts as an unnecessary constraint on site identification.

Figures 5.1A – B demonstrate examples from the validation process, immediately evident is the impact upon the feasibility of a site. These features are often located centrally to a site, creating complex geometries within site polygons and ultimately reducing the favourability of a site under high-level assessment. The Churchill Square site displayed below is largely hampered by a network of ventilation units, reducing the modelled site from a possible 1500m^2 to 350m^2. For the residential site (5.2B) there is number of smaller sporadic rooftop superstructures consisting of skylights and ventilation units which LIDAR was sensitive to, with the resulting polygon appearing unsuitable for construction.

With these examples and validation determining rooftop superstructures to have a high impact on site availability it suggests a methodological extension would be necessary to improve the size and functionality of identified sites.

Figure 5.2: Impact of Rooftop superstructures on Site availability. 5.2A (Left) is a section Churchill Square which is impacted by ventilation units. Figure 5.2B (right) is a housing block with sporadic rooftop superstructures.

The impact of rooftop superstructures upon remote sensing is not of direct interest within the literature, however, authors often elude to methodologies which remove their impact upon modelling. The first of which calls into question this study's use of a supplied LIDAR DSM over a LIDAR point cloud. The EA's 1m DSM requires a lower computation capacity for handling and thus a greater applicability to city-wide analysis, however Tseng & Hung (2016) suggest that the use of LIDAR point cloud would allow the differentiation between rooftop structures and the rooftop structure which could then be segmented to extract a flat rooftop surface. The author claims this differentiation would be achieved through the first return signals of these pronounced features and last return signals from the rooftop surface. Such an approach differs from the EA DSM which was produced from last return LIDAR signals (DEFRA, 2019) alone, identifying human structures and substantial vegetation features which have a single interaction with the LIDAR pulse (Wang *et al*., 2009).

Furthermore, the use of LIDAR point cloud and multiple return signals would allow the mitigation of inaccuracies caused by overhanging vegetation. Although not identified within the Brighton study area this topic sees literature interest as it is a frequently occurring issue in many urban scenes (Jiao & Deng, 2016). Techniques will analyse the multiple return of LIDAR signals in order differentiate between the complex returns of vegetative structures against the last returns of building structures (Fogl & Moudry, 2016). Although authors indirectly comment upon the use of multiple return signals to get the true last return of a rooftop (Nguyen *et al*., 2012), the omittance of rooftop superstructures from a DSM through last return signals has limited literature focus.

The ability for multiple return LIDAR to detect these rooftop features has little literature support, with comprehensive studies where its inclusion would be advantageous, making no reference to such an approach (eg. Palmer *et al*., 2015). However, if further research efforts are conducted proving its success, multiple return LIDAR would be a user-friendly, reproducible methodology to mitigate the impact of rooftop superstructures upon site identification.

Arguably the more popular approach is the modelling of roof planes without pronounced features. Urban 3D modelling is often the next stage for LIDAR studies and has seen extensive literature development. Within this literature authors frequently model rooftops from their primitive geometric elements, the vertices, edges, faces of the main structure (Wang *et al*., 2015). The building planes are subsequently modelled from these elements to avoid complex rooftop superstructures (Jung *et al*., 2017) which are often referred to as noise within larger modelling scenarios (Cheng *et al*., 2017).

5.2.3 'Zigzag' Edge

In nearly all site polygons there was some degree of boundary 'Zigzag'. This characteristic is most frequently the result of ArcGIS modelling, however further factors such as overhanging vegetation can also cause this boundary inaccuracies. Modelling errors occur when ArcGIS fails to generate a smooth boundary across multiple cells and instead tracing the boundary of the coarse LIDAR cells. This results in 'Zigzag' polygon boundary which often impacts upon available construction space, especially sites of smaller size. This phenomenon is exemplified in figure 5.3; the residential example (Left) shows a narrow rooftop which is consistently reduced in width due the failure of modelling to generate a straight boundary.

Figure 5.4: Example of a residential block which has been heavily impacted by the ZigZag edge generated through modelling

Figure 5.3: Example of concrete raised rooftop perimeter typical of many buildings in Brighton.

The problem of 'cleaning up' rooftop detection for automated processes has seen literature interest with authors incorporating further modelling steps to improve output quality. Most applicable to this study however, is the Rooftop fencing problem identified by Seo *et al*., (2014). The authors attributes 'Zigzagging' within LIDAR derived polygons to the raised fencing seen around rooftop perimeters, figure 5.4 shows the typical characteristics of the rooftop safety feature. This narrow feature is often not identified by LIDAR's 1m and 0.5m point density and results in the zigzag boundary as ArcGIS modelling traces the raster perimeter. Seo *et al*., (2014) further state the impact this effect has upon the automation of LIDAR building detection and proposed an additional modelling step using Minimum Boundary Rectangles (MBR). This technique generates a boundary from the geometric centroid outwards to avoid tracing confusion when the model reaches the raised perimeter, creating a smoother boundary (Freeman & Shapira, 1975). For BrightNest modelling, the implementation of this processing step would improve the accuracy of Phase One site identification and raise site favourability due to the larger available area.

However, authors still report accuracy decreases in perimeter tracing with irregular rooftop shapes (Seo *et al*., 2014; Gilani *et al*., 2015), prompting further development into rooftop detection of complex roof shapes. Alternatively, processing could include a step to simplify geometrical shapes of the existing sites, a stage which could benefit BrightNest site identification. The complex characteristics of Brighton's building plans often results in obscure sites of irregular geometry being identified in Phase One, however in practice, these sites offer little development potential. If these sites could be geometrically simplified it would improve the quality of sites put forward into Phase Two and further aid future automation of the process. A methodology possible of achieving this is proposed by Gooding *et al*., (2015) whom demonstrated how geometric alterations to 2D Building Plan data can aid further processing. Shown in figure 5.5, the authors segment polygons by their internal concave angles allowing protrusions from the rectangular building body to be removed and the building plan simplified. Incorporation of this step into BrightNest processing would allow the simplification of OSBH dataset prior to Phase One identification, improving the suitability of final sites for construction. Furthermore, as identified by (Sao *et al*., 2014), the simplification of site boundaries would further aid any future automation of site identification.

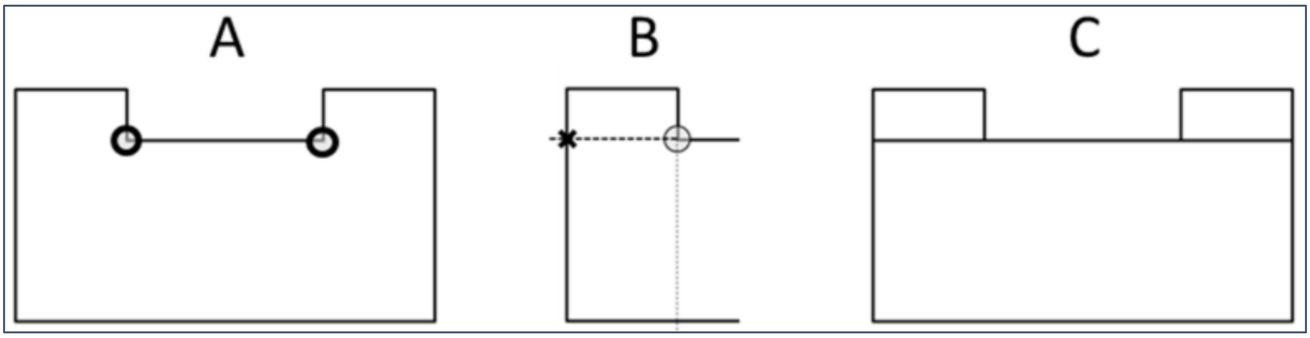

Figure 5.5: Taken from Gooding et al., (2015) the figure demonstrates the authors simplification approach to complex building plan polygons with internal concave angles.

5.3 Phase Two Sensitivity Analysis

Phase Two of the methodology, determination of site ranking scores, is also subject to a validation assessment. This step a is critical inclusion for both Research Aims; it acts to raise confidence within the BrightNest site identifications, reassuring potential developers within Brighton that effective site ranking has been undertaken. However, it also provides insights into the criteria most likely to impact final site development under modified input parameters, an important consideration for further application of this methodology. This analysis will also emphasise the change upon the highest 5 scored sites, to further consolidate their performance.

Validation was achieved through the application of One At a Time Sensitivity Analysis (OAT-SA), this process was ran to a minor (1%) and major (5%) adjustment extent to investigate the behaviour of criteria and site rankings under changed criterion weightings (Priority Eigenvectors, table 4.3). Using the original bin extents outlined in table 4.4, sensitivity was measured through the change in Suitability Groups class frequency, reported as percentage change values in tables 5.4 and 5.5. For example, for 1% adjustment extent (table 5.4), 5 sites were classified within the least favourable

Suitability Grouping 1. Adjusting the Area Criterion +2% and the other 5 criteria -1% led to 40% increase in Suitability Grouping 1 sites (7 Sites). This was then iteratively performed on each criterion, adjusting one by +2% and the other 5 -1%. Trends discussed within these graphs are sectioned below for clarity:

The 100% decrease in Suitability Category 6

It must firstly be stated that the most prominent trend within both tables, the 100% decrease present in 11/12 suitability category 6 cells, is a product of the employed methodology. Decreasing 5 criterion whilst increasing 1 will inevitably lead to an overall decrease in final site rankings.

Solar Potential criterion's high sensitivity to 1% adjustment

Assessment of 1% adjustments (table 5.4) reveals that the Solar Potential Criterion is the most sensitive to change, with a reciprocal average percentage change value of 74%, which is explained through the initial high weighting of 0.44 assigned to the criterion. However, adjustment of the Solar Criterion results in an unexpectedly large decrease in site performance with a 55% decrease in Suitability Category 5 sites. This is best explained by the criterions high weighting which has a greater influence upon the site rankings, resulting in a greater change in suitability rankings.

Solar Potential criterion's low sensitivity to 5% adjustment

The apparent stability shown in this scenario is the exacerbated by the 10% reduction in Solar weighting in other iterations which subsequently leads to high degree of change due to its high initial weighting of 0.44. This is confirmed by Solar Potential and Area criteria's lower percentage change within suitability grouping 5, as their high weighting reduces the impact of the major adjustment.

Protection Criterions increased influence under 5% adjustment

Under a major adjustment of 5% the protection criteria became the most sensitive criterion with a 198% change whereas under minor adjustment it is the lowest at 27%. This discrepancy identified by the extreme weightings is the result of heavily skewed initial scoring with 236/255 sites not impacting upon a listed building and been awarded the highest score. Therefore, upon a dramatic increase in the criterions weight there is an extensive change in site scoring.

Table 5.2 identifies that under minor weighting adjustment Building Protection is the most stable parameter, with other low scoring criteria of Coastal Distance and Green Spaces having a higher average percentage change value. Whereas Solar Potential is identified as a sensitive criterion in relation to the other highly weighted criteria of Area. This knowledge has important implications for the further application of this model, where experts may weight the criteria slightly differently. For instance, model application to an urban area of high historic value would have the assurance that the model will not be dominated by Building Protection criteria. These same insights can be gained from the major adjustment sensitivity analysis.

Sensitivity analysis can also be assessed in relation to individual site performance, this approach will improve confidence in the determined site rankings and aid future development of the BrightNest project. Analysis of the highest 5 scoring sites that were previously identified in figure 4.4 show that inset A located on Churchill Square was the most stable site under both adjustment extents. Whilst the site identified in inset B dropped was subject to greater fluctuation and would be a less assured site for development.

Table 5.3: OAT-SA 5% Adjustments – Percentage Change

			Suitability Grouping Percent Change					
Suitability Category	**Bin**	**Phase 2 Frequen.**	**Area (%)**	**Green (%)**	**Prot. (%)**	**Solar (%)**	**Slope (%)**	**Coast (%)**
1	2.06	**5**	80	100	80	80	80	60
2	2.73	**5**	80	160	80	60	100	-20
3	3.4	**14**	792	578	835	164	492	407
4	4.07	**99**	-14	16	-10	70	36	50
5	5.41	**124**	-78	-82	-86	-74	-85	-81
6	5.58	**8**	-100	-100	-100	-100	-100	-100
Reciprocal Average			190	172	198	91	149	113

Table 5.2: OAT-SA 1% Adjustments – Percentage Change

			Suitability Grouping Percent Change					
Suitability Category	**Bin**	**Phase 2 Frequen.**	**Area (%)**	**Green (%)**	**Prot. (%)**	**Solar (%)**	**Slope (%)**	**Coast (%)**
1	2.06	**5**	40	40	-40	80	40	40
2	2.73	**5**	-20	-20	20	-20	-20	-20
3	3.4	**14**	100	64	-28	135	50	50
4	4.07	**99**	40	35	-20	55	40	36
5	5.41	**124**	-37	-29	20	-55	-32	-29
6	5.58	**8**	-100	-100	-37	-100	-100	-100
Reciprocal Average			56	48	27	74	47	45

Table 5.3. 1% Adjustment Sensitivity Analysis of highest scoring sites

		Adjustment Ranking					
Figure 4.4	**Original Rank**	**Area**	**Green**	**Protection**	**Solar**	**Slope**	**Coast**
A (Top)	3	3	4	3	5	3	3
A (Bottom)	1	1	1	1	1	1	1
B (Left)	2	2	3	2	4	2	2
B (Right)	4	7	7	4	7	5	4
C	5	4	3	5	2	4	5

Table 5.4. 5% Adjustment Sensitivity Analysis of highest scoring sites

		Adjustment Ranking					
Figure 4.4	**Original Rank**	**Area**	**Green**	**Protection**	**Solar**	**Slope**	**Coast**
A (Top)	3	3	5	5	5	3	4
A (Bottom)	1	1	4	1	1	1	3
B (Left)	2	2	9	4	4	2	1
B (Right)	4	5	10	7	7	4	2
C	5	4	1	2	2	7	9

6 Conclusions

6.1 Limitations

The Analysis / Discussion chapter of this project brought attention to a small number of errors which had a varying degree of error upon the project outputs. The earliest and most arguably impactful decision is the criteria included within analysis, this is common problem within the MCDM literature which is often presented without justification for the oversight of parameters (eg. Garni & Awasthi, 2017). It is ultimately a question of resources, there are countless input parameters within the scope of this study yet the evaluation of a greater a number was deemed unachievable within the allotted time frame. However, with further application of rooftop SSA analysis users should attempt to incorporate a building ownership criterion as raised within this discussion. A further methodological feature which influenced interpretation was the design of the initial criteria scoring system. Literature commonly incorporates a uniform reclassification scoring across the criteria (Kamdar *et al*., 2019) whereas in this study the reclassification scoring ranged from 4-7. This had unforeseen impacts which were prominent within sensitivity analysis and impacted upon interpretations.

As aforementioned, analysis identified discrepancies within the Phase One remote sensing of this study. These errors were arguably the result of an oversimplified solution to a complex topic of rooftop modelling for which there is significant literature focus and development. It has been identified that further advanced processing and automation of the process would improve roof plane modelling, subsequently improving the accuracy and quality of site identification. However, as commented by Palmer *et al*., (2015); for rooftop analysis there is no single methodology which outperforms alternatives when considerations are made for speed, detail and user-friendliness. Therefore, upon reproduction and modification of this methodology it is advisable for a user to consider the impact further detail and accuracy would have upon the accessibility of this airspace assessment tool.

6.2 BrightNest Quantification

Brighton holds 255 sites capable of BrightNest development, totalling 51538m^2 which equates to £247 million worth of development potential using house price per m^2 for Brighton (ONS, 2017b). Introducing ranking into the final assessment reveals there are 8 sites of suitability grouping 6 and 124 of suitability grouping 5, which would act as preferred sites for development within the city and should receive initial focus for further detailed assessment. Furthermore, the undertaking of Sensitivity Analysis confirms that even under differing weighting conditions these high scoring sites would likely remain the most suitable and therefore represent a sound initial site identification for future developers.

However, as identified an analysis of spatial distribution, the majority of these high scoring sites are located within campus style buildings which promotes both challenges and opportunities. These challenges are well represented by The Royal Sussex County Hospital. A Campus style site with good development opportunity but in reality, is unfeasible for construction due to the sensitivity of building use and would inevitably be removed from further site options analysis. On the other hand, site prevalence on campus style buildings presents opportunities to work with land owners to propose initiative schemes and bring forward larger development opportunities.

Therefore, this project would recommend that the Churchill Square shopping centre represents the greatest opportunity for BrightNest development. With a high number of sites already identified and likely a greater number once the impacts of rooftop superstructures have been mitigated, which have scored consistently high throughout assessment, this region would be an attractive option for developers and the local authority alike.

6.3 Final Comments

With the design stages of the BrightNest project completed the project would now require efforts within a number of aspects to prove its commercial viability. Whether the modules are suitable medium-term housing, will their operation remain carbon neutral and would stakeholder investment be economically attractive, are some of the next challenges to address for further development. This study acts to answer a further practical implication of quantifying its application potential and identifying the most favourable sites within Brighton.

To achieve its study aims, this study split site identification and site ranking into two separate phases. Phase One employed reproducible and computationally light remote sensing processes to identify sites physically capable for BrightNest development. With a very suitable 255 sites identified for Phase Two analysis it showed that the constraint criteria were well designed and its application to further urban areas would be an interesting research incentive. However, arguments would exist around the sites simplicity in processing which allowed LIDAR based errors to impact the quality of identified sites. Modification of this methodology to erase these errors would be advisable upon further application.

Phase two of the study ranked Phase One sites to 6 pre-determined criteria through application of well-developed AHP and Pairwise Comparison techniques. In the absence of an expert opinion, this study further proposed the literature-based determination of criterion weightings, whilst the approach is not common within the literature it could be a viable alternative to an expert opinion with further development. Phase Two identified 8 sites within the highest suitability grouping which were found to be consistent under changed criterion weightings and would be ‘safe bet’ for potential developers. This study also showed the affinity of site identification with Campus building typologies, knowledge that would serve an important inclusion to the further expansion of the BrightNest project.

Finally, the application of these methodologies to airspace and rooftop development opportunities acts as a development within the extensive literature surrounding AHP and MCDM. Much of the existing research is focused upon renewable energy and urban infrastructure, however with the ongoing housing crisis the application of these methodologies as a high-level assessment for airspace development opportunities could serve an important role in the near future.

7 References

- **Al-Shalabi M.A**., Mansor S.B., Ahmed N.B., Shiriff R. **(2006).** “GIS Based Multicriteria Approaches to Housing Site Suitability Assessment”. *Shaping the Change* – XXIII FIG Congresss, Munich, Oct 8-13, 2006.
- **Aly S**., Vrana I. **(2008)**. “Evaluating the knowledge, relevance and experience of expert decision makers utilizing the Fuzzy-AHP”. *Agricultural Economics*, 11, pp. 529-535. DOI:10.17221/264-AGRICECON.
- **Ammar H**., Boukebbous S.E., Benbaha N. **(2018)**. “Photovoltaic Water Pumping System Site Suitability Analysis Using AHP GIS method In Southern Algeria”. *4th International Conference on Renewable Energies for Developing Countries (REDEC)*, pp. 1-5. DOI: 10.1109/REDEC.2018.8597643.
- **Anderson K**., Hancock S., Disney M., Gaston K.J. **(2015)**. “Is waveform worth it? A comparison of LIDAR approaches for vegetation and landscape characterisation*”. Remote Sensing in Ecology and Conservation*, 2(1). DOI: doi.org/rse2.8.
- **Asajereg A**., Soleymani M., Sheikhdavoodi M.J. **(2017)**. “A GIS-based Fuzzy-AHP method for the evaluation of solar farms locations: Case study in Khuzestan province, Iran”. *Solar Energy,* pp. 342-353. DOI: 10.1016/j.solener.2017.05.075
- **Awrangjeb M.,** Zhang C., Fraser C.S. **(2013). “**Automatic extraction of building roofs using LIDAR data and multispectral imagery.” *ISPRS Journal of Photogrammetry and Remote Sensing,* 83, pp. 1-18. DOI: 10.1016/j.isprsjprs.2013.05.006.
- **Awwad T.M**., Zhu Q., Du Z., Zhang Y. **(2010).** “An improved segmentation approach for planar surfaces from unstructured 3D point clouds.” *The Photogrammetric Record,* 25(129). DOI: https://doi.org/10.1111/j.1477-9730.2009.00564.x.
- **Ballarini I**., Corrado V., Madonna F., Paduos S., Ravasio F. **(2017).** “Energy refurbishment of the Italian residential building stock: energy and cost analysis through the application of the building typology”. *Energy Policy*, 105, 148-160. DOI: 10.1016/j.enpol.2017.02.026.
- **Baseer M.A.,** Rehman S., Meyer J.P., Alam M.D. **(2017)**. *“*GIS-Based site suitability analysis for wind farm development in Saudi Arabia”. Energy, 141, pp. 1166-1176. DOI: doi.org/10.1016/j.energy.2017.10.016.
- **Bazan-Krzywoszańska A.,** Mrówczyńska M., Skiba M., Łączak A. **(2016)**. “Economic conditions for the development of energy efficient civil engineering using RES in the policy of cohesion of the European Union (2014–2020). Case study: The town of Zielona Gora”. *Energy and Buildings*, 118, pp. 170-180.
- **Bellakaout A.,** Cherkaoui M., Ettarid M. **(2016). “**Touzani A. Automatic 3D extraction of buildings vegetation and roads from LIDAR data*”. The International Archives of the Photogrammetry of Remote Sensing and Spatial Information Sciences*, XLI-B3, pp. 173-180. DOI: 10.5194/isprs-archives-XLI-B3-173-2016
- **Berry R.,** Livesley S.J., Aye L. **(2013). “**Tree canopy shade impacts on solar irradiance received by building walls and their surface temperature”. *Building and Environment,* 69, pp. 91-100. DOI: 10.1016/j.buildenv.2013.07.009.
- **BMI Icopal.** (No Date). Building Regulations. *BMI.* http://www.icopal.co.uk/Products/Single_Ply_Roofing/monarplan-single-ply-roofing/building-regulations.aspx. Accessed: 26/06/19.
- **Dong J.**, Zhuang D., Xu X., Ying L. (2008). “Integrated Evaluation of Urban Development Suitability Based on Remote Sensing and GIS Techniques - A Case Study in Jingjinji Area, China”. *Sensors*, 8(9), pp. 5975-5986. DOI: 10.3390/s8095975.

- **Borcs A.,** Nagy B., Benedek C. **(2017).** "Instant Object Detection in LIDAR Point Clouds"*. IEEE Geoscience and Remote Sensing*, 14(7), pp. 992-996. DOI: 10.1109/LGRS.2017.2674799
- **Boyd A. (2013)**. Engines of our Ingenuity: No. 2879. Empty Shipping Containers. https://www.uh.edu/engines/epi2879.htm. Accessed: 12/06/19
- **BrightNest.eu. (2017).** University of Brighton. http://www.brightnest.eu/. Accessed: 03/06/19.
- **Brighton and Hove City Council. (2014).** Annex 3 – Housing Implementation Strategy, revised September 2014. https://www.brighton-hove.gov.uk/sites/brighton-hove.gov.uk/files/FINAL%20annex%203%20%28mar%202016%29.pdf. Accessed: 20/06/19.
- **Brighton and Hove City Council. (2016).** Brighton and Hove City Council's Development Plan. https://www.brighton-hove.gov.uk/sites/brighton-hove.gov.uk/files/FINAL%20version%20cityplan%20March%202016compreswith%20forward_0.pdf. Accessed: 20/06/19.
- **Brown K.M.,** Hambridge C.H., Brownett J.M. **(2016).** "Progress in operational flood mapping using satellite synthetic aperture radar (SAR) and LIDAR". *Progress in Physical Geography*, 40(2). DOI: 10.1177/0309133316633570.
- **Bunruamkaew L**., Murayam Y. **(2011)**. "Site suitability evaluation for ecotourism using GIS & AHP: A case study of Surat Thani province, Thailand." *Procedia – Social and Behavioural Sciences*, 30, pp. 637-646.
- **Burrough P.A**., McDonell R.A. **(1998)**. Principles of Geographical Information Systems (Oxford University Press, New York), 190 pp.
- **Cawood A.J.** Bond C.E., Howell J.A., Butler R.W.H. Totake Y. **(2017).** "LiDAR, UAV or compass-clinometer? Accuracy, coverage and the effects on structural models". *Journal of Structural Geology,* 98, pp. 67-82. DOI: 10.1016/j.jsg.2017.04.004.
- **Cetinkaya C**., Ozceylan E., Erbas M., Kabak M. **(2016).** GIS-based Fuzzy MCDA Approach for Siting Refugee Camp: A Case Study for Southeastern Turkey. International Journal of Disaster Risk Reduction, 18, DOI: 10.1016/j.ijdrr.2016.07.004.
- **Chen D.,** Zhang Z., Mathiopoulos P.T., Huang X**. (2014). "**A methodology for automated segmentation and reconstruction of urban 3-D buildings from ALS point clouds". *IEEE Journal of Selected Topics - Applied Earth Observations Remote Sensing*, 7(10), pp. 1-19.
- **Cheng Y.,** Zhang Y., Wu Q., Yabin X., Remil O., Wei M., Wang J. **(2017). "**Urban building reconstruction from raw LiDAR point data". *Computer Aided Design,* 93, pp. 1-14. DOI: 10.1016/j.cad.2017.07.005.
- **Chow A.,** Fung S.A., Li S. **(2014)**. "GIS modelling of solar neighbourhood potential at a fine spatiotemporal resolution." *Buildings,* 4, pp. 195-206. DOI: 10.3390/buildings4020195.
- **Chu B. (2017).** "Tory cuts to affordable homes responsible for UK housing crisis, says National Housing Federation". The Independent (Online); London London: Independent Digital News & Media. Accessed: 17/07/19.
- **DEFRA. (2019). 'LIDAR Composite DSM – 1m'** https://environment.data.gov.uk/dataset/6f51a299-351f-4e30-a5a3-2511da9688f7. Last Accessed: 23/08/2019.
- **Degirmenci S.***,* Bingol F., Sofuoglu S.C. **(2018). "**MCDM analysis of wind energy in Turkey: decision making based on environmental impact". *Environmental Science and Pollution Research,* 25(20), pp. 19753-19766. DOI: 10.1007/s11356-018-2004-4
- **Department Communities and Local Government (DCLG). (2016).** Consultation on Upward Extensions in London, February 2016. DCLG Publications.

- **Du X.**, Wang Z. **(2018).** Optimizing monitoring locations using a combination of GIS and fuzzy multi criteria decision analysis, a case study from the Tomur World Natural Heritage site. *Journal for Nature Conservation,* 43, pp. 67-74. DOI: 10.1016/j.jnc.2018.02.004.
- **Eberstadt S. (2004).** "The Rucksack House" – Architectuul http://architectuul.com/architecture/backpack-house. Accessed: 12/06/19.
- **Economist**. (**2015). "**Welcome to the Drone Age". https://www.economist.com/science-and-technology/2015/09/26/welcome-to-the-drone-age. Accessed: 24/06/19.
- **Environment Agency**. **(2019)**. "LIDAR composite DTM – 1m." https://data.gov.uk/dataset/6a117171-5c59-4c7d-8e8b-8e7aefe8ee2e/lidar-composite-dtm-1m. Accessed: 18/06/19.
- **Errouhi A.A.**, Bahi L., Latifa O**. (2018). "**Evaluation of landfill site choice using AHP and GIS case study: Oum Azza, morocco". *MATEC Web of Conferences,* 149. DOI: 10.1051/matecconf/201714902047.
- **ESPG**. (**2014**). "Solar Farm Site Identification." http://esgp.co.uk/renewable-energy-site-identificatio/solar-farm-site-identification/. Accessed 04/08/19.
- **Ewertowski M**.**W.,** Tomczyk A.M., Evans D.J.A., Roberts D.H., Ewertowski W. **(2019).** "Operational Framework for Rapid, Very-high Resolution Mapping of Glacial Geomorphology Using Low-cost Unmanned Aerial Vehicles and Structure-from-Motion Approach"**.** *Remote Sensing*, 11(1), pp. 65-72. DOI: 10.3390/rs11010065.
- **Foroughu S.**, Rasal M.A. **(2016). "**Housing renovation priority in the fabric texture of the city using the analytic hierarchy model (AHP) and geographic information system (GIS): A case study of Zanjan City, Iran." *The Egyptian Journal of Remote Sensing and Space Science*, 19(2), DOI: 10.1016/j.ejrs.2016.05.001
- **Fischler M.A.** & Bolles R.C. **(1981).** "Random Sample Consensus: A Paradigm for Model Fitting with Apphcatlons to Image Analysis and Automated Cartography". *Artificial Intelligence Centre*, SRI International, 24(6).
- **Fitzpatrick S.** & Pawson H. **(2016).** "Fifty years since Cathy Come Home: critical reflections on the UK homelessness safety net." *International Journal of Housing Policy*, 16(4), pp. 543-555.
- **Fogl M.**, Moudry V. **(2016).** "Influence of vegetation canopies on solar potential in urban environments". *Applied Geography*, 66, pp. 73-80. 10.1016/j.apgeog.2015.11.011.
- **Frank A.U.** & Mark M. **(1991). "**Language issues for Geographical Information Systems". In Maguire D. J., Goodchild M. F., Rhind D. W., (editors) *Geographical Information Systems: Principles and Applications*, London: Longmans Publishers, 1, 147-163.
- **Freeman H.**, Shapira R. **(1975)** "Determining the minimum-area encasing rectangle for an arbitrary closed curve". *Communications of the ACM*, 18(7), pp. 409-413.
- **Fu P.**, Rich P.M. **(2000).** The Solar Analyst 1.0 Manual. Helios Environmental Modeling Institute (HEMI), USA. http://professorpaul.com/publications/fu_rich_2000_solaranalyst.pdf. Last Accessed: 22/08/2019.
- **Garni H.Z.,** Awasthi A. **(2017)**. "Solar PV power plant site selection using a GIS-AHP based approach with application in Saudi Arabia". *Applied Energy,* 206, pp. 1225-1240. DOI: 10.1016/j.apenergy.2017.10.024.
- **Georgiou A.**, Skarlatos D. **(2016). "**Optimal site selection for sitting a solar park using multi-criteria decision analysis and geographical information systems". *Geoscientific Instrumentation, Methods and Data Systems,* 5, pp. 321-332. DOI: doi.org/10.5194/gi-5-321-2016.

- **Gilani S.A.N**., Awrangjeb M., Lu G. **(2015).** "Fusion of LIDAR data and multispectral imagery for effective building detection based on graph and connected component analysis". *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*. Volume XL-3/W2, 2015 PIA15+HRIGI15 – Joint ISPRS conference 2015, 25–27 March 2015, Munich, Germany.
- **Gooding J.,** Edwards H., Giesekam J., Crook R. **(2013)**. "Solar City Indicator: a methodology to predict city level PV installed capacity by combining physical capacity and socio-economic factors". *Solar Energy*, 95, pp. 325–335. DOI: https://doi.org/10.1016/j.solener.2013.06.027.
- **Gooding J.**, Crook R., Tomlin A.S. **(2015).** "Modelling of Roof Geometries from Low-resolution LiDAR Data for City-Scale 2 Solar Energy Applications using a Neighbouring Buildings Method." *Applied Energy,* 148, pp. 93-104.
- **GOV.UK. (2017).** *Rural Population and Migration – Official Statistics.* https://www.gov.uk/government/statistics/rural-population-and-migration.
- **Gopalakrishnan R.**, Thomas V.A., Coulston J.W., Wynne R.H. **(2016).** "Prediction of Canopy Heights over a Large Region Using Heterogeneous Lidar Datasets: Efficacy and Challenges." *Remote Sensing,* 7(9), pp. 11036-11060. DOI: https://doi.org/10.3390/rs70911036.
- **Grand View Research. (2018).** 'Modular Construction Market Analysis, Market Size, Application Analysis, Regional Outlook, Competitive Strategies, And Segment Forecasts, 2018 To 2025.' https://www.grandviewresearch.com/industry-analysis/modular-construction-market/methodology. Accessed: 11/06/19.
- **Greater London Authority. (2012). '**Barriers to Housing Delivery.' https://www.london.gov.uk/sites/default/files/gla_migrate_files_destination/Barriers%20to%20Housing%20Delivery%202012.pdf. Last Accessed: 22/07/19.
- **Gumusay M.U.,** Koseoglu G., Bakirman T. **(2016). "**An assessment of site suitability for marina construction in Istanbul, Turkey, using GIS and AHP multicriteria decision analysis"**.** *Environmental Monitory and Assessment*, 188(12), pp. 667-675. DOI: 10.1007/s10661-016-5677-5.
- **Hancock S.,** Anderson K., Disney M., Gaston K.J. **(2017)**. "Measurement of fine-spatial-resolution 3D vegetation structure with airborne waveform lidar: Calibration and validation with voxelised terrestrial lidar." *Remote Sensing of Environment*, 188, pp. 37-50. DOI: 10.1016/j.rse.2016.10.041.
- **Haala N.**, Brenner C., Anders K.H. **(1998).** "3D urban GIS from laser altimeter and 2D map data". *International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, 32, pp. 339-346.
- **Halligan L. (2018).** 'Home truths – Part I: The UK housing crisis in six graphs'. UnHerd – Capitalism. https://unherd.com/2018/04/home-truths-part-i-uk-housing-crisis-six-graphs/. Last Accessed: 15/07/19.
- **Hariz H.A.,** Donmez C., Sennaroglu B**. (2017). "**Siting of a central healthcare waste incinerator using GIS-Based Multi-Criteria Decision analysis". *Journal of Cleaner Production*, 166, DOI: 10.1016/j.jclepro.2017.08.091.
- **Harrison H. (1969). "**Surnames of the United Kingdom: A Concise Etymological Dictionary". Pp. 230. ISBN 978-0806301716.
- **Hornberger G**., Spear R. **(1981)**. "An approach to the preliminary analysis of environmental systems." *Journal of Environmental Management*, 7, pp. 7-18.
- **Hugenholtz C.H.,** Whitehead K., Brown O.W., Barchyn T.E., Moorman B.J., Leclair A. **(2013). "**Geomorphological mapping with a small unmanned aircraft system (sUAS): feature detection and accuracy assessment of a photogrammetrically-derived digital terrain model." *Geomorphology*, 194, pp. 16–24. https://doi.org/10.1016/j.geomorph.2013.03.023.

- **Javadian M**., Shamskooshki H., Momeni M. (2011). "Application of Sustainable Urban Development in Environmental Suitability Analysis of Educational Land Use by Using Ahp and Gis in Tehran". *Procedia Engineering*, 21, pp. 72-80. DOI:10.1016/j.proeng.2011.11.1989.
- **Jiao J**., Deng Z. "Individual Building Rooftop and Tree Crown Segmentation from High-Resolution Urban Aerial Optical Images". *Journal of Sensors,* 11, DOI: 10.1155/2016/1795205.
- **Kabak M.,** Erbas M., Cetinkaya C., Ozceylan E**. (2018). "**A GIS-based MCDM approach for the evaluation of bike-share stations". *Journal of Cleaner Pollution*, 201, pp. 49-60. DOI: 10.1016/j.jclepro.2018.08.033.
- **Kachri G. (2009). "**Parasite Ecologies: Extending Space Through Diffusion - Limited Aggregation Models". University College London. Bartlett School of Graduate Studies. Unpublished. Master Thesis.
- **Kabir G,** Hasin A. A. **(2011)**. "Comparative analysis of AHP and Fuzzy AHP models for multicriteria inventory classification". *International Journal of Fuzzy Logic Systems*, 1(1).
- **Kamdar I.,** Ali S., Bennui A., Techato K., Jutidamrongphan W. (**2019). "**Municipal solid waste landfill siting using an integrated GIS-AHP approach: A case study from Songkhla, Thailand". *Resources, Conservation and Recycling, 149,* pp. 220-235, DOI: 10.1016/j.resconrec.2019.05.027.
- **Kara C.,** Doratli N. **(2012). "**Application of GIS/AHP in siting sanitary landfill: a case study in Northern Cyprus." *Water Management,* 30(9), pp. 966-80. DOI: 10.1177/0734242X12453975.
- **Kar B.** & Hodgeson M.E. **(2008)**. "A GIS-based model to determine site suitability of emergency evacuation shelters". *Transaction in GIS*, 12(2). DOI: https://doi.org/10.1111/j.1467-9671.2008.01097.x.
- **Kay J. (2017).** 'How to solve the UK housing crisis'. FT.com; London. The Financial Times Limited. https://search-proquest-com.ezproxy.brighton.ac.uk/docview/1974472077/citation/FCE38A7BFA0F4D74PQ/1?accountid=9727. Accessed: 03/06/19.
- **Khabtibi S.M.R.,** Najafi V.H. **(2016). "**An Analysis of Space Distribution and Applied Site Selection of Urban Lands with an Emphasis on Access to Civil Services based on AHP Model in GIS Environment (Case Study: Qazvin Institutes of Higher Education)". *Space Ontology International Journal*, 5, 1, pp. 55-67.
- **Kondo M.C**., Fluehr J.M., McKeon T., Branas C.C. **(2018). "**Urban Green Space and its Impact on Human Health"*. International Journal of Environmental Research for Public Health*, 15(3), pp. 445.
- **Knapp S.** and Coors V. **(2008)**. "The use of eparticipation in public participation: the VEPs example". In: Coors, V., Rumor, M., Fendel, E., Zlatanova, S. (Eds.), Proc. of the Urban Data Management Society Symposium 2007 (UDMS Annual 2007), Stuttgart, Germany, 10–12 October, pp. 93–104.
- **Knight Frank. (2014).** ' A premium you can bank on – Knight Frank Waterfront Index'. https://content.knightfrank.com/research/646/documents/en/2014-2198.pdf. Accessed 17/07/19.
- **Knight Franks Research**. **(2017).** 'Skyward'. https://content.knightfrank.com/research/1400/documents/en/skyward-2017-5111.pdf. Accessed: 05/06/19
- **Li Z.,** Fan Z., Shen S. **(2018)**. Urban Green Space Suitability Evaluation Based on

the AHP-CV Combined Weight Method: A Case Study of Fuping County, China. Sustainability, 10. doi:10.3390/su10082656

- **Malczewski J. (1999).** 'GIS and Multicriteria Decision Analysis'. John Wiley and Sons, New York.
- **Manache G.,** Melching C.S. **(2008).** "Identification of reliable regression- and correlation-based sensitivity measures for importance ranking of water-quality model parameters". *Environmental Modelling & Software,* 23, pp. 549-562. DOI: 10.1016/j.envsoft.2007.08.001
- **Mara Build. (2010). '**Bedford Court Mansions'. http://www.marabuild.co.uk/bedford-court-mansions. Accessed: 11/06/19.
- **Mass H.G.** & Vosselman G. **(1999). "**Two algorithms for extracting building models from raw laser altimetry data". *ISPRS Journal of Photogrammetry and Remote Sensing*, 54, 2, pp. 153–163. https://doi.org/10.1016/S0924-2716(99)00004-0.
- **Merrouni A.A.,** Mezrhab A., Mezrhab A. **(2016). "**PV sites suitability analysis in the Eastern region of Morocco". *Sustainable Energy Technologies and Assessments*, 18, pp. 6-15.
- **Merrouni A.A.,** Elalaoui F. E., Hennioui A., Mezrhab A., Mezrhab A. **(2018). "**A GIS-AHP combination for the sites assessment of large-scale CSP plants with dry and wet cooling systems. Case study: Eastern Morocco". *Solar Energy,* 166, pp. 2-12. DOI: 10.1016/j.solener.2018.03.038.
- **Mind.org. (2017). '**Brick by Brick: A review of mental health and housing'.
- https://www.mind.org.uk/media/26223865/brick-by-brick-a-review-of-mental-health-and-housing.pdf. Last Accessed: 03/08/19.
- **Ministry of Housing, Communities and Local Government (MHCLG). (2018).** *Planning Reform: Supporting the high street and increasing the delivery of new homes.* MHCLG Publications.
- **Modis International. (2015)**. 'Why Build with Shipping Containers?' https://www.modsinternational.com/why-build-with-shipping-containers/. Last Accessed 10/07/19.
- **Modulek. (2014). '**Jewell Academy'. https://www.modulek.co.uk/images/. Accessed: 11/06/19.
- **Morton P.J. (2013).** 'A Global perspective in the development and distribution of VCMs'. In Proceedings of the Northumbria Research Conference, Newcastle, UK, 15–16 May.
- **Nathan S. (2018). '**Modular Construction: Flat-pack to the future'. The Engineer, Civil & Structural. https://www.theengineer.co.uk/modular-construction-flat-pack/.
- **Nguyen H.T.,** Pearce J.M. Harrap R., Barber G. **(2012). "**The Application of LiDAR to Assessment of Rooftop Solar Photovoltaic Deployment Potential in a Municipal District Unit", *Sensors,* 12, pp. 4534-4558. DOI: 10.3390/s120404534.
- **Nunes N.C.G. (2009).** "Exploitation of shipping containers for housing." Master Thesis, University of Beira Interior, Portugal (in Portuguese).
- **Office for National Statistics. (2017a).** 'People Population and community - Population estimates.' https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationestimates. Accessed: 03/06/19.
- **Office for National Statistics. (2017b). '**House price per square metre and house price per room, England and Wales: 2004 to 2016'. https://www.ons.gov.uk/releases/housepricepersquaremeterandhousepriceperroomenglandandwales2004to2016. Last Accessed 23/08/2019.
- **Office for National Statistics. (2018). '**Estimating the impact urban green space has on property price'.

https://www.ons.gov.uk/economy/nationalaccounts/uksectoraccounts/compendium/economicreview/july2018/estimatingtheimpacturbangreenspacehasonpropertyprice. Accessed: 04/08/2019.

- **Ooshuizen R.,** Palit N., Dove C., Begin R., Mason D., Bagnall V. **(2016). ‘**London’s Rooftops: Potential to Deliver Housing’. HTA for Apex Airspace development. http://www.apexairspace.co.uk/wp-content/uploads/2017/03/HTA-P-Rooftop-Development-Report.pdf. Last Accessed: 22/07/19.
- **Ordnance Survey. (No Date). ‘**Data collection, management and analysis’. https://www.ordnancesurvey.co.uk/international/knowledge/data-collection-management.html. Last Accessed: 22/07/19.
- **Ordnance Survey. (2014**). ‘Using machine learning to build the future of 3D mapping’. https://www.ordnancesurvey.co.uk/blog/2014/12/using-machine-learning-to-build-the-future-of-3d-mapping/#more-17827. Accessed: 17/06/19.
- **Ordnance Survey. (2018).** ‘Microsoft and Ordnance Survey join forces to teach machines how to identify types of roofs’. https://www.ordnancesurvey.co.uk/about/news/2018/microsoft-os-hack.html. Accessed: 17/06/19.
- **Pasalari H.,** Nodehi N.R., Mahvi A.H., Yaghmaeian K., Charrahi Z. **(2019)**. “Landfill site selection using a hybrid system of AHP-Fuzzy in GIS environment: A case study in Shiraz city, Iran”. *MethodsX*, 6, pp. 1454-1466. DOI: 10.1016/j.mex.2019.06.009.
- **Palmer D.,** Cole I., Betts T., Gottschalg R. (2016). “Assessment of potential for photovoltaic roof installations by extraction of roof tilt from light detection and ranging data and aggregation to census geography”. *IET Renewable Power Generation*, 10(4), 467-473. doi: 10.1049/iet-rpg.2015.0388
- **Palmer D.,** Gottschalg R., Betts T. **(2019)**. “The future scope of large-scale solar in the UK: Site suitability and target analysis”. *Renewable Energy*, 133, pp. 1136-1146.
- **Parliamentary Office of Science & Technology. (2016). ‘**Green Space and Health’. POSTnote 538, October 2016. https://researchbriefings.parliament.uk/ResearchBriefing/Summary/POST-PN-0538. Accessed: 04/08/2016.
- **Peng J.,** Peng F.L. **(2018).** “A GIS-based evaluation method of underground space resources for urban spatial planning: Part 1 methodology”. *Tunnelling and Underground Space Technologies*, 74, pp. 82-95. https://doi.org/10.1016/j.tust.2018.01.002.
- **Radwan A.H. (2015). “**Containers Architecture - Reusing Shipping Containers in making creative Architectural Spaces”. *International Journal of Scientific & Engineering Research*, 6(11), pp. 1562-1576. ISSN 2229-5518.
- **Rainato R.,** Picco L., Cavalli M., Delai F., Ravazzolo D. **(2013). “**Evaluation of short-term geomorphic changes along the Tagliamento river using LiDAR and terrestrial laser scanner surveys.” *Journal of Agricultural Engineering*, 44(2). DOI: 10.4081/jae.2013.256
- **Rich P.M.,** Dubayah R., Hetrick W.A., Savinf S.C. **(1994). “**Using Viewshed Models to Calculate Intercepted Solar Radiation: Applications in Ecology”. *American Society for Photogrammetry and Remote Sensing Technical Papers*, 524–529.
- **Saadaoui H.,** Ghennioui A., Ikken B., Rhinane H., Maanan M. **(2019). “**Using GIS and photogrammetry for assessing solar photovoltaic potential on Flat Roofs in urban area case of the city of Ben Guerir / Morocco”. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, Volume XLII-4/W12, pp. 155-166. DOI: https://doi.org/10.5194/isprs-archives-XLII-4-W12-155-2019.

- **Sanchez-Lozano J.M.,** Teruel-Solano J., Soto-Elvira P.L., Garcia-Cascales M.S. **(2013).** "Geographical Information Systems (GIS) and Multi-Criteria Decision Making (MCDM) methods for the evaluation of solar farms locations: Case study in south-eastern Spain". *Renewable and Sustainable Energy Reviews*, 24, pp. 544-556. DOI: 10.1016/j.rser.2013.03.019.
- **Sampath A.** & Shan J. **(2010). "**Segmentation and reconstruction of polyhedral building roofs from aerial LIDAR point clouds". *IEEE Transactions in Geoscience – Remote Sensing*, 48(3), pp. 1554-1567. DOI: 10.1109/TGRS.2009.2030180.
- **Sargent I.,** Holland D., Harding J. **(2015). "**The Building Blocks of User-Focused 3D City Models". *ISPRS International Journal of Geo-information*, 4(4), pp. 2890-2904. https://doi.org/10.3390/ijgi4042890.
- **Sankey T.,** Sankey J.B., Donager J., McVay J. **(2017). "**UAV LIDAR and hyperspectral fusion for forest monitoring in the Southwestern *USA". Remote Sensing of Environment*, 195, pp. 30-43. DOI: 10.1016/j.rse.2017.04.007.
- **Sarling J. (2013). '**Building for the future: Where should we build houses to stimulate the economy?' The Political Quarterly , 84 (1), pp. 144 – 150.
- **Sensoy G.** & Utsun B. **(2018). "**Traces of The Past Utopias in Contemporary Architecture: Parasitic Architecture**."** International Journal of Architecture and planning, 6(1), pp. 170-195.
- **Seo S.,** Jeongho L., Yongil K. **(2014). "**Extraction of Boundaries of Rooftop Fenced
- Buildings From Airborne Laser Scanning Data Using Rectangle Models". IEEE Geoscience and Remote Sensing Letters, 11(2). DOI:10.1109/LGRS.2013.2263575.
- **Shelter.org. (2017).** 'The impact of Housing problems on mental health'. https://england.shelter.org.uk/__data/assets/pdf_file/0008/1397267/2017_04_19_Research_Report_-_The_impact_of_housing_problems_on_mental_health.pdf. Accessed: 01/06/19.
- **Shelter. (2018).** '320,000 people in Britain are now homeless, as numbers keep rising'. https://england.shelter.org.uk/media/press_releases/articles/320,000_people_in_britain_are_now_homeless,_as_numbers_keep_rising. Last Accessed: 22/07/19.
- **Silverman B**. **(1986)**. "Density estimation for statistics and data analysis". NewYork, NY: Chapman and Hall/CRC.
- **Smith D.**P., Holt L. **(2007)**. "Studentification and 'apprentice' gentrifiers within Britain's provincial towns and cities". *Environment and Planning A* , 39 , pp. 142 – 161.
- **Solazzo D**., Sankey J.B., Sankey T., Munson S.M. **(2018)**. "Mapping and measuring aeolian sand dunes with photogrammetry and LiDAR from unmanned aerial vehicles (UAV) and multispectral satellite imagery on the Paria Plateau, AZ, USA". *Geomorphology*, 319, pp. 174-185. 10.1016/j.geomorph.2018.07.023.
- **Tarsha-Kurdi F.,** Landes T., Grussenmeyer T., Koehl M. **(2007)**. "Model-driven and data-driven approaches using LIDAR data : analysis and comparison"*. International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, 36, pp. 87-92.
- **TerraDrone**. (2018). 'Basingstoke 3D City Model'. https://terra-drone.eu/en/basingstoke-3d-city-model/. Last Accessed: 18/06/19.
- **Vertex Modelling**. (2013). 'Edinburgh 3D Model'. http://vertexmodelling.co.uk/products/Edinburgh-3d-model/. Last Accessed: 18/06/19.
- **Tarsha-Kurdi F**., Landes T., Grussenmeyer P., Koehl . **(2007)**. "Model driven and data driven approaches using LIDAR data: analysis and comparison." . *International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, 36*.
- **Town and Country Planning**. **(2015).** 'General Permitted Development – England - Order 2015'. http://www.legislation.gov.uk/uksi/2015/596/contents/made. Last Accessed: 22/07/19.

- **Tseng Y.H.,** Hung H.C. **(2016).** Extraction of building boundary lines from airborne LIDAR point counts". *The International Archives of the Photogrammetry Remote Sensing and Spatial Information Sciences*, Volume XLI-B3, 2016 XXIII ISPRS Congress, 12–19 July 2016, Prague, Czech Republic.
- **Vijayalaxmi J**. **(2010).** "Towards sustainable architecture – a with Greentainer." *Local Environment*, 15(3), pp. 245-259.
- **Vo A.V.,** Truong-Hong L., Laefer D.F. Bertolotto M. **(2015)**. "Octree-based region growing for point cloud segmentation". *ISPRS Journal of Photogrammetry and Remote Sensing*, 104, pp. 88-100.
- **Wang C.,** Meneti M., Stoll M.P., Alessandra F., Belluco E., Marani M. **(2009)**. "Separation of Ground and Low Vegetation Signatures in LiDAR Measurements of Salt-Marsh Environments". *IEEE Transactions on Geosciences and Remote Sensing*, 47(7), pp. 2014-2023. DOI:10.1109/TGRS.2008.2010490
- **Wang J**. & Shan J. **(2009).** "Segmentation of LIDAR point cloud for building extraction". American Society for Photogrammetry and Remote Sensing, Annual Conference, Baltimore – Maryland, March 9-13.
- **Wang H**., Zhang W., Chen Y., Chen M., Yan K. **(2015). "**Semantic Decomposition and Reconstruction of Compound Buildings with Symmetric Roofs from LiDAR Data and Aerial Imagery". *Remote Sensing,* 7(10), pp. 13945-13974. DOI: doi.org/10.3390/rs71013945.
- **Walden C. (2018).** 'Classifying the UK's roofs from aerial imagery using deep learning with CNTK – Microsoft.' https://blogs.technet.microsoft.com/uktechnet/2018/04/18/classifying-the-uks-roofs-from-aerial-imagery-using-deep-learning-with-cntk/. Last Accessed: 26/06/19.
- **Wiginton L.K**., Nguyen H.T., Pearce J.M. **(2010)**. "Quantifying rooftop solar photovoltaic potential for regional renewable energy policy". *Computers, Environment and Urban Systems*, 34 (4), pp. 345–357.
- **Woch F.***,* Hernik J., Linke H., Sankowski E., Beczkowska M., Noszczyk T. **(2017)**. *"*Renewable energy and rural autonomy: A case with generalisations". *Polish Journal of Environmental Studies*, 26, pp. 2823-2832.
- **Xu K.,** Kong C., Li J., Zhang L., Wu C. **(2011)**. "Suitability evaluation of urban construction land based on geo-environmental factors of Hangzhou, China." *Computers and Geoscience*, 8, pp. 992-1002. DOI: org/10.1016/j.cageo.2011.03.006
- **Xu Z.,** Liao H. **(2014).** "Intuitionistic Fuzzy Analytic Hierarchy Process". *IEEE transaction on Fuzzy Systems*, 22:4, 749-761. DOI:10.1109/TFUZZ.2013.2272585
- **Xu B.**, Jiang W., Shan J., Zhang J., Li L. **(2016).** "Investigation on the Weighted RANSAC Approaches for Building Roof Plane Segmentation from LiDAR Point Clouds". *Remote Sensing,* 8(1), pp. 5-12.
- **Yan J.**, Jiang W., Shan J. **(2012). "**Quality analysis on RANSAC based roof facets extraction from airborne LIDAR data"*. International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, Volume XXXIX-B3. XXII ISPRS Congress, 25 August – 01 September 2012, Melbourne, Australia.
- **Yi C.,** Zhang Y., Wu Q., Xu Y., Remil O., Wei M. **(2017).** "Urban building reconstruction from raw LiDAR point data". *Computer-Aided Design,* 93, pp. 1-14. DOI: https://doi.org/10.1016/j.cad.2017.07.005
- **Zhang H.**, Li Y., Li H. **(2013). "**Multi-agent simulation of the dynamic evolutionary process in Chinese urban housing market based on the GIS: The case of Beijing". *Automation in Construction,* 35, pp. 190-198. DOI: 10.1016/j.autcon.2013.05.010.
- **Zion Market Research. (2019).** 'Global Modular Construction Market Will To Reach USD 175.15 Billion By 2025'. https://www.globenewswire.com/news-

release/2019/05/06/1817435/0/en/Global-Modular-Construction-Market-Will-To-Reach-USD-175-15-Billion-By-2025-Zion-Market-Research.html. Last Accessed: 11/06/19

8 Appendices

8.1 Appendix 1 - Solar Radiation Equation (ESRI, No Date)

Global Radiation

$$\mathbf{Dir_{tot} = \sum Dir_{\theta,\alpha}} \quad \mathbf{(1)}$$

Direct Radiation

$$\mathbf{Dir_{\theta,\alpha} = S_{const} * \beta^{m(\theta)} * SunDur_{\theta,\alpha} * COS(AngIn_{\theta,\alpha})} \quad \mathbf{(2)}$$

Where:

- **SConst** — The solar flux outside the atmosphere at the mean earth-sun distance, known as solar constant. The solar constant used in the analysis is 1367 W/m2. This is consistent with the World Radiation Center (WRC) solar constant.
- **β** — The transmissivity of the atmosphere (averaged over all wavelengths) for the shortest path (in the direction of the zenith).
- **m(θ)** — The relative optical path length, measured as a proportion relative to the zenith path length (see equation 3 below).
- **SunDurθ,α** — The time duration represented by the sky sector. For most sectors, it is equal to the day interval (for example, a month) multiplied by the hour interval (for example, a half hour). For partial sectors (near the horizon), the duration is calculated using spherical geometry.
- **SunGapθ,α** — The gap fraction for the sun map sector.
- **AngInθ,α** — The angle of incidence between the centroid of the sky sector and the axis normal to the surface (see equation 4 below

Diffuse Radiation

Difθ,α = Rglb * Pdif * Dur * SkyGapθ,α * Weightθ,α * cos(AngInθ,α) (3)

where:

- **R_{glb}** — The global normal radiation (see equation 6 below).
- **P_{dif}** — The proportion of global normal radiation flux that is diffused. Typically it is approximately 0.2 for very clear sky conditions and 0.7 for very cloudy sky conditions.
- **Dur** — The time interval for analysis.
- **$SkyGap_{\theta,\alpha}$** — The gap fraction (proportion of visible sky) for the sky sector.
- **$Weight_{\theta,\alpha}$** — The proportion of diffuse radiation originating in a given sky sector relative to all sectors (see equations 7 and 8 below).
- **$AngIn_{\theta,\alpha}$** — The angle of incidence between the centroid of the sky sector and the intercepting surface.

8.2 Appendix 2 – Aerial Validation Data

Table 8.1: Raw aerial validation results

Polygon ID	Impact of Rooftop Features	Impact of 'ZigZag'	Flat Rooftop
56	High	Low	Yes
113	High	Medium	Yes
63	Low	Low	Yes
146	low	low	Yes
33	low	low	yes
65	low	low	Yes
246	medium	low	yes
118	Medium	high	Yes
192	High	Medium	Yes
17	Low	Low	No
179	High	Low	Yes
120	High	Low	Yes
220	-	-	-
48	low	low	flat
135	low	Medium	flat
30	High	Medium	Maybe
193	Medium	High	Yes
99	Low	Medium	Maybe
144	Low	High	Yes
150	High	low	Maybe
176	low	low	yes
167	low	low	yes
225	High	Low	yes
79	low	low	yes
37	Medium	Low	Yes
209	Low	medium	yes
216	Low	medium	Maybe
172	low	Medium	no
160	high	low	yes
164	Low	medium	yes
119	low	low	maybe
130	Medium	low	yes
226	Low	low	yes
100	High	medium	yes
178	Medium	Medium	yes
236	high	Medium	yes

8.3 Appendix 3 – Sensitivity Analysis Data

Table 8.2: Area 5% Adjustment

Bin	*Frequency*
2.06	9
2.73	9
3.4	125
4.07	85
5.41	27
5.58	0

Table 8.3: Green Space 5% Adjustment

Bin	*Frequency*
2.06	10
2.73	13
3.4	95
4.07	115
5.41	22
5.58	0

Table 8.4: Protection 5% Adjustment

Bin	*Frequency*
2.06	9
2.73	9
3.4	131
4.07	89
5.41	17
5.58	0

Table 8.5: Solar Potential 5% Adjustment

Bin	*Frequency*
2.06	9
2.73	8
3.4	37
4.07	169
5.41	32
5.58	0

Table 8.6: Slope 5% Adjustment

Bin	*Frequency*
2.06	9
2.73	10
3.4	83
4.07	135
5.41	18
5.58	0

Table 8.7: Coastal Distance 5% Adjustment

Bin	*Frequency*
2.06	8
2.73	4
3.4	71
4.07	149
5.41	23
5.58	0

Table 8.8: Area 1% Adjustment

Bin	*Frequency*
2.06	7
2.73	4
3.4	28
4.07	139
5.41	77
5.58	0

Table 8.9: Green Space 1% Adjustment

Bin	*Frequency*
2.06	7
2.73	4
3.4	23
4.07	134
5.41	87
5.58	0

Table 8.10: Protection 1% Adjustment

Bin	*Frequency*
2.06	3
2.73	6
3.4	10
4.07	79
5.41	149
5.58	5

Table 8.11: Solar Potential 1% Adjustment

Bin	*Frequency*
2.06	9
2.73	4
3.4	33
4.07	154
5.41	55
5.58	0

Table 8.12: Slope 1% Adjustment

Bin	*Frequency*
2.06	7
2.73	4
3.4	21
4.07	139
5.41	84
5.58	0

Table 8.13: Coastal Distance 1% Adjustment

Bin	*Frequency*
2.06	7
2.73	4
3.4	21
4.07	135
5.41	88
5.58	0