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Assessing the Relationships between Demographics, Street Trees and Visual Recognition of Urban Buildings

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ABSTRACT: As more "green" cities are emerging in the 21st century, human recognition of urban buildings can be obstructed by increasing amount of vegetation in urban areas. While the architectural designs of urban buildings are more complicated than before, architects often seek the maximum exposure of the design to public. If vegetation obstructs significant portions of an innovative design of a building, the visual value and attractiveness of the building can diminish greatly. People may not able to retain much visual and spatial memories about a building or even a city because their views are obstructed. This paper begins with a thorough review of current and past literature about the relationship between buildings, street trees, and visibility in urban environments. The purpose of this research is to identify factors that influence visual recognizability of buildings in an urban environment. First, a method called "green ratio" is proposed to quantify the amount of greenery that people can see on the ground. The result can be beneficial to urban planners, architects, city planners, urban geographers, and city tourism board for better integrating vegetation and buildings in a cityscape. The goal of understanding people's visual recognition of urban objects is to raise inhabitant's satisfaction, capture their attention, and make strong impressions towards the city.

KEYWORDS: urban geography, environmental planning, environmental perception, human-environment geography, urban planning, urban design, urban morphology, and demographics

Introduction

Visibility and viewshed analyses have been applied to many disciplines to identify and solve spatial problems regarding which objects can or cannot be seen from observation points across natural terrain or a built environment. With the availability of the Geographic Information System (GIS) toolkits, visibility studies have become increasingly accessible in different disciplines, such as architecture (Turner et al. 2001), archaeology (Fisher et al. 1997; Paliou 2011), urban planning (Danese 2009), human behaviour, (Pearson et al. 2014) and forestry (Dean et al. 1997). The current approaches used in visibility and viewshed studies heavily focus on the accuracy of viewshed delineation techniques. Little research exists in the evaluation of the accuracy of these techniques when they are applied to an urban environment. A lack of studies concerning how these techniques empirically reflect actual human perception and recognition toward urban environments can be observed.

In addition to the concepts of visibility and viewshed, one of the fundamental concepts explaining an individual's perception and navigation across space in an urban environment is their ability to identify and recognize surrounding urban objects. Lynch (1960) suggests that structuring and identifying the environment is an important trait shared by all mobile animals and man. As most of the previous research heavily focuses on the visibility and viewshed delineation, little research exists regarding the expansion of the scope of studying how an urban object is perceived spatially with the investigation of recognizability of urban objects. It can be argued that the recognizability of urban objects such as buildings can be at least perceived as an important element of wayfinding, similar to visibility (Lynch 1960).

Lynch asserts the strategic link in the process of wayfinding is what he considers as the environmental image, which indicates the generalized mental picture of the exterior physical world held by a person. In a cluttered environment, permeated with innumerable high-rise buildings and skyscrapers, a person may use recognizable buildings as landmarks for spatial and navigational references. Numerous buildings can be seen from any vantage point within an urban area, but not all of them are recognizable—many are nondescript and could be confused with another. The recognizability of a building is a function of the surrounding topography, characteristics of the structure, the building's architectural design, and personal experience. The latter is in a realm of psychology and human behavior and does not serve as the primary focus of this research.

Echoing Lynch's ideas in the 1960s, cities today are concerned about their "image" as a tourist destination (Heath et al. 2000). Heath et al. (2000) stated that tourist publications, postcards, souvenirs, and shows on television indicate that the form of the urban skyline is an extremely important component of the city's image. Investigating how the spatial configuration of a city creates this kind of image for both inhabitants and tourists is vital. Buildings are anchors in many urban realms, and, therefore, their unique recognition and visualization contribute to a city's visual signature. Urban planners, landscape designers, and geographers may be able to preserve the image of a city by scrutinizing the attributes of the recognizability of urban buildings. In simple terms, they can ensure that buildings, especially the iconic ones, are clearly recognized and visualized from various distances without hindering the view of vegetation. As a result, it is vital to understand how buildings can be recognized in such a complex urban environment.

Again, despite a considerable number of scholarly works devoted to visibility analysis (Bartie et al. 2011; Yin et al. 2012; Fisher et al. 1997), as yet no research the author is aware of has addressed recognizability of urban buildings from the perspective of geospatial information science. This paper offers a preliminary research of the subject of the recognizability of spatial objects in a geospatial context. The result of this paper can be applied in the areas of the perception of landscape, cities' image creation, visual quality assessment, urban planning, building design, and spatial configuration of a city.

By offering methods to better understand and quantify recognizability of spatial objects in urban environment, this research aims to investigate the spatial relationship between the observer, obscuring vegetation, and the targets (buildings) and how this relationship influences one aspect of the recognizability of the targets in an urban setting.

The research presented here specifically attempts to provide answers to the following questions:

1. How buildings are recognized by inhabitants in an urban environment?
2. How can the "recognizability" of buildings be defined and quantified from a geospatial perspective?
3. What are the factors that may potentially influence and predict the recognizability of buildings in an urban environment?
4. What are the implications of investigating factors of the recognizability of buildings in an urban environment?

This study attempts to predict the potential attributes that influence the recognizability of buildings in New York City. This research is conducted to better understand how distance, socio-demographic factors, and vegetation influence the recognizability of buildings within the study area. The goal of this research is not to develop a comprehensive and exhaustive model of predicting recognizability. Instead, this paper is a preliminary exploration that attempts to investigate factors of recognizability and suggests how they might be developed and tested through various approaches from a statistical and spatial perspective.

Literature Review

Human interactions with their surroundings are profoundly complex in a cityscape or an urban environment. A three-dimensional (3D) approach can ratify and capture the multi-dimensional reality of how human beings recognize and perceive their surroundings. Urban landscape elements, such as the topological relations between spatial objects, spatial configuration of the city, and visual observation of spatial objects, create the image of a city (Lynch 1960; Appleyard 1969; Heath & Smith, 2000). The image provides city planners, designers, and officials a reference to better construct the urban form of this city and improve environmental quality or aesthetics.

The topological relations between spatial objects are widely studied in the field of city model creation (Brenner et al. 2001; Frueh et al. 2004; Shibasaki 1992), however, these studies overlook the obstruction of vegetation during the process of model creation. The presence of vegetation can also serve as a major obstacle in conventional isovist and visibility studies. Vegetation can become one of the potential factors that influence the recognizability of urban buildings. The literature review below attempts to investigate how previous researches have failed in recognizing the power of vegetation in diminishing one's ability to recognize the target object.

After all, it is necessary to differentiate "seeing the object" from "recognizing the object." This difference is particularly influential in urban studies. As the previous scholarly works heavily relied on the studies of visibility (Turner et al. 2001; Yang et al. 2007; Yin et al. 2012), recognizability of urban objects can help better to construct the form of a cityscape by city planners and officials, where it mimics the reality of how humans perceive the city (Appleyard 1969; Zube et al. 1982). Appleyard (1969) in his early study mentioned that planners and architects will possess a powerful design tool if one can predict how well the buildings and structures of the city known. To do this, it is vital to study why buildings are known by discovering the attributes of buildings and structures that capture the attention of the inhabitants of the city.

Visibility of Buildings

A complex and populous urban environment such as the New York City comprises a matrix of skyscrapers with different heights, shapes, and designs. Skyscrapers and buildings can be easily accessed by pedestrians, tourists, or New Yorkers within walking distance. However, objects, such as urban trees, overpasses, or signs, which may be situated between an individual and the building may act as an obstruction in clearly seeing and recognizing the buildings. Technically, a line of sight (LOS) is "a line between two points that shows the parts of surface along the line that are visible to or hidden from an observer" (Bratt & Booth 2002). The viewshed, according to Bratt and Booth (2000), identifies the cells in a raster database, which are visible from one or more observation points and/or lines. Lines of sight are used for constructing this viewshed.

Yin et al. (2012) incorporated the concept of LOS in the visibility analysis of buildings through a two-step process: first, they determined which are the buildings that need to be evaluated in the analysis. The diagram shown in Figure 1 demonstrates the position of three buildings along the projected LOS, from V' to T'. The first building a 1 is the nearest to the vantage point and completely blocks the LOS. As a result, the following buildings in the sequence (a 2 and a 3) are not considered for calculation in the visibility analysis.

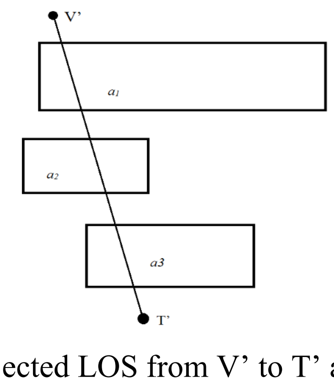


Figure 1. Projected LOS from V' to T' and building profiles

Yin et al. (2012) also used the parallel project ion approach to find the building polygon s that block ed the LOS. This approach applies the simple logic that if there is a building or object intersecting with the LOS, the observer's view of the target object is blocked and, thus, neither the observer point nor the target point is visible. A projected plane is made perpendicular to the LOS. The building polygon is then projected on the projected plane. If V' is located inside the projected polygon of the building, the LOS is blocked by that building. A drawback of this approach of visibility analysis is that it takes a lot of time to construct projected planes in a complex urban environment with thousands of buildings.

Yin et al. (2012) also highlighted that technical challenges exist when calculating the visibility across urban buildings with this projected plane approach. Their approaches are not well-suited in the actual urban environment, as many other vision-obstructing objects such as vegetation are situated between the V' and T'. These vision-obstructing objects can completely or partially block the visibility of the target from the viewer. For instance, an individual still can see the target building partially through spaces between tree branches and underneath tree canopies. Visibility also varies seasonally during "leaf-off" conditions. Oftentimes, the viewer has managed to correctly recognize and identify the building even though only a small portion of the building is visible. An individual can easily recognize the famous Empire State Building in New York City from different observation points in the city, even though only the roof line of the building may be visible. This indicates there is some sort of spatial relationship between the observation points, the target building, and the ability of an individual to not only see but also recognize the target. Yin et al. (2012) and other authors' findings do not explain this spatial relationship in the context of recognizability in their studies.

Visibility and Vegetation

Vegetation not only provides a significant scenic value in a concrete jungle; it also acts a local landmark and tourist attraction in a mega-city. For instance, Central Park in New York City is not only considered one of most famous parks in the world but also serves as a popular landmark and icon of the Big Apple. As urban trees and other vegetation have been widely introduced in metropolitan cities, vegetation has become an essential element in high-density urban areas (Yuan et al. 2017). Architecturally, trees increase visual diversity and complexity to an urban environment (Rapoport & Hawks 1970). Vegetation in urban environments also functions as a screen or buffer between incompatible land uses (Smardon 1988). Past studies that have investigated the function of urban vegetation have mostly focused on human's cognitive, psychological, and physiological wellness (Sheets et al. 1991; Smardon 1988). As already mentioned in the previous section of this paper, no research has yet identified the spatial relationship of urban vegetation and observer's ability to recognize the building accurately along the line of sight.

For instance, the presence of dense trees in urban parks in New York can pose a significant obstacle on the generated visibility and the result of viewshed. Joggers and visitors in Central Park may not be able to see or distinguish the number of neighboring buildings on 5th Avenue correctly, as canopies of trees and vegetation may block the view according to different seasons and various degrees of the transparency of trees. Rød et al. (2009) developed a weighing function to express the transparency of trees in calculating the total visibility at a point. The following formula shows that weight "w" is the relative blocking magnitude of trees while V_{bf} is the visibility of based on a surface that includes both buildings and forest:

$$V = w_{bf} V_{bf} + w_b V_b$$

where V_b is the visibility based on a surface that only includes buildings (Rød et al. 2009).

Weights are relatively subjective according to one's interpretation of transparency. Rød et al. (2009) did not mention in detail the criteria to determine the weight or the blocking magnitude. Dean (1997) proposed another approach to improve the prediction of visibility of trees in forests using estimates of opacity and visual permeability value. The density of trees in an urban park is not uniform in reality. Some areas may have patches of dense vegetation and trees. The variation in the tree density during spring and fall seasons can be much greater than that in summer and winter. Instead of differentiating regions with different vegetation density, Dean's permeability coefficient is applied to the entire region, assuming the density of vegetation is constant.

On the other hand, a high density of vegetation or full foliage can block significant portions of faces of urban buildings. An urban environment comprises complicated built structures and developments, all of which can introduce complications in visibility analysis. As mentioned in the previous section, increasing the numbers of trees and parks in cities not only obstructs the view of many built structures but also obstructs a significant portion of a structure, thus, reducing the recognizability of that structure to inhabitants.

The concept of "Recognizability"

In simple terms, an innovative concept of "recognizability" can be defined as the ability of a viewer to correctly identify and recognize an object across a geographical space. It is also the ability of a person to identify an object from their knowledge of its appearance or characteristics. While GIS can map visibility to demonstrate how a point is visible, no previous research introduced the application of GIS to investigate the attributes of influencing recognizability of urban objects.

The distance between an observer and the target objects (buildings) serves as an essential variable in visibility analysis (Pearson et al. 2014). Principally, the visibility of an object declines when the distance between the observer and the target object increases. However, the recognizability of the same target object operates in a different fashion. Recognizability comprises spatial components as well. In a complex and clustered urban environment, the target building such as a skyscraper appears as visible to an observer at a near distance.

Heath et al. (2000) explained the "distant view" of a building can be defined as the one in which the building forms only one element of a larger scene. In Heath's early study (1971), he suggested that the scene and the building itself at a distant range of 1 kilometer are perceived as flat patterns. Color variations are insignificant compared to tonal variations. The finer detail of that building is lost as well. Heath et al. (2000) stated that distance also tends to decrease involvement.

However, the recognizability of this target can be low, although the distance between the observer and the target is small. Heath et al. (2000) mainly focused on quantification of the visual complexity of tall buildings at a distance range. They did not consider the surrounding vegetation, which may increase the visual complexity, because the observer may have difficulty identifying or recognizing the target accurately (i.e., correctly naming the building or identifying the numbers of the building). This illustration explains a twofold scenario: first, the fundamental concept of visibility is dissimilar to recognizability; and second, the distance and the recognizability of objects may not always conform to a linear relationship. Figure 3 further explains the relationship between visibility and recognizability. The building in the center of the Figure 2 is visible within the entire region (both blue and shaded areas). However, it can only be completely recognized by observers within the shaded region. One of the key concepts presented here is that the building can be visible from far away but not from the observer's location at the blue region. The spatial relationship between the observer, the trees situated along the line of sight, and the target building can be the potential factor influencing the recognizability of the target building.

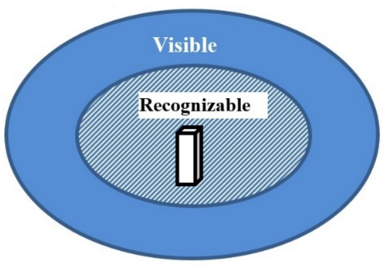
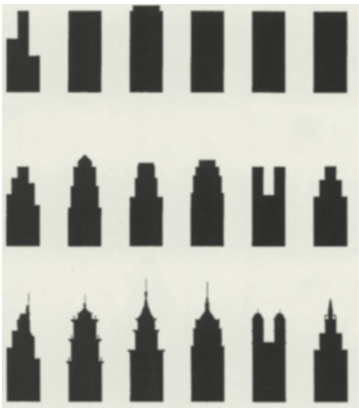


Figure 2. The spatial relationship between "visibility" and "recognizability"

Recognizability, physical attributes of buildings, and surrounding vegetation

Heath et al. (2000) found that the perceived complexity of buildings can be attributed to their silhouette and the articulation or subdivision of their façade. Figure 3 and figure 4 demonstrate the different building profiles proposed by Heath et al. (2000). They suggested that changes in the profiles of urban buildings can be linked to changes in the perceived complexity of building façades. In fact, the surrounding vegetation near a tall building may increase or decrease its perceived complexity. For instance, if the vegetation obscures the most complicated section of the building façade, the perceived complexity may diminish. Heath et al. (2000) proposed a qualitative and quantitative approach to investigate such an inter-relationship between human perception and physical attributes of tall buildings. Unfortunately, Heath et al. (2000) did not provide any information regarding how vegetation may alter human perception in this context. This flaw of their research encourages this research to investigate how vegetation can obstruct human perception and recognition of buildings.



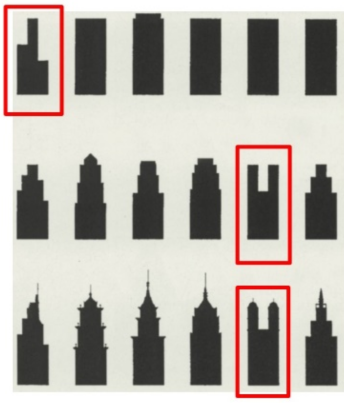


Figure 3 and 4. Different building profiles proposed by Heath et al. (2000)

Similar to the concept of complexity illustrated in Heath et al.'s (2000) study, the concept of the recognizability of a building can also be understood through the human perception and the physical attributes of buildings. In regard to building shapes, as demonstrated by Heath et al. (2000) in Figure 4, some buildings have different towers that are not linked through a shared ground base (figure 5). A method of obtaining good recognizability is determined by learning how viewers correctly identify one basic aspect of a building's recognizability —whether or not the observable portions of one or more buildings are connected and hence constitute a single building or are not connected and hence constitute two or more buildings.

Green Ratio and Recognizability

To better understand what proportion of street trees and shrubs obstruct the target building, a concept of "Green Ratio" is proposed. This ratio is inspired by the work of Yang et al. (2009), who developed a "Green View" factor to quantify the amount of greenery that people can see on the ground. The goal of their research was to develop a Green View factor to evaluate the visibility of urban forests. The Green View factor was estimated through a combination of field surveys and photographic interpretations and tested in Berkeley, California. The pixels of greenery in each photograph are selected and counted in each photograph. The selected pixels were then divided by the total pixels of the image to get the ratio of the greenery to the total area of the photo. Yang et al. suggest a big limitation of their work:

"…the visual quality decided by subtle characteristics of the greenery within view, such as the arrangement of vegetation and buildings, pattern of leaf distribution, and varied colors and

textures of foliage, were not addressed in this study. However, those characteristics can have influence on perceptions of the urban forest." (Yang et al. 2009, 103)

The Green Ratio method proposed here is different from that of Yang el al. (2009) Green View method. The Green Ratio offers an improved approach to investigate the ratio of greenery to surrounding buildings. The Green Ratio calculates the proportion of greenery that obstructs façades of the target building. This method can help to study the arrangement of vegetation and buildings in which Yang et al. study did not address. The following is a detailed explanation of how the Green Ratio is obtained.

First, 36 photos of 12 buildings (3 photos for each building) were taken in lower Manhattan in the New York City in late June in 2017. 12 Buildings are selected randomly within a 0.5-mile radius of the high pedestrian volume locations according to the bi-annual pedestrian traffic counts report from the New York City Department of Transportation (the map see Appendix). It is assumed that the selected buildings may have high exposure to pedestrians on weekdays. Buildings near these high pedestrian volume locations are important to pedestrians' visual memories and recognition of the surrounding area for wayfinding or navigation (Lynch 1969). The 12 buildings are in fact of different usages of commercial, residential, and governmental activities. All these buildings are not the worldly renowned buildings such as the Empire State Building, or the Chrysler Building to minimize the recognition bias. Three photos will be taken for each building from a near, medium-range, and far distance. The target area is highlighted with yellow line in a sample photo as seen in figure 5.

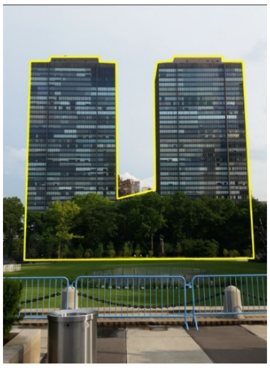


Figure 5. Sample photo for calculating the Green Ratio

Pixels of all greenery that obstruct the building within the highlighted region are selected by the Magic Ward tool in Adobe Photoshop. Pixels of the buildings within the highlighted region are also selected by the Magic Ward tool in Adobe Photoshop. The Histogram function in Adobe Photoshop shows the selected pixel counts. Green Ratio is obtained for each photo by the following equation:

$$Green\ Ratio = \frac{Pixel\ counts\ of\ obstructed\ greenary\ within\ the\ hightlighted\ region}{Pixel\ counts\ of\ enrire\ target\ building\ within\ the\ highlighted\ region}$$

Results

Table 1 in the Appendix illustrate the green ratio of each photo. There are three photos with zero green ratio. There is no greenery within the highlighted region in each of these three photos. Photos of the Majestic Apartment and Peter Copper Village yield the highest green ratio. Trees and shrubs obstruct over at least 50% of the building facade in the photo of the Majestic Apartment building and Peter Copper Village.

After the establishment of a Green Ratio, it is important to further investigate how humans recognize the buildings from real photos to better understand how recognizability of buildings are attributed. A quantitative survey can be developed to gather responses on how participants recognize the correct number of buildings in each photo. The number of buildings in each photo basically reflects the topological relation of that particular building or buildings. For instance, a building with two towers and one shared base may appear as two separate buildings if trees and shrubs cover the base floors. Hence, it is more meaningful to ask participants to evaluate the number of buildings appearing in the photo rather than the names of the building.

We may assume the building with high green ratios yield less correct responses because street vegetation covers significant amount of building façade. Demographic factors such as age, sex, gender, ethnicity, education, residency, frequency of downtown visits, and previous New York City visits may also influence the rate of correct responses or the recognizability of buildings. We can also apply regression analysis to predict the factors that yield correct responses on the survey.

Discussions and conclusions

This research does not aim to provide an exhaustive description of the survey and advanced regression model; instead, presenting a preliminary method called "Green Ratio" to investigate visual recognition or recognizability of urban buildings. From the literature review in the previous section, the recognizability of a building can reach maximum if an observer is located close enough to the building where there is no obstruction of vegetation blocking the building façade along his line of sight. Another critical factor of predicting visual recognition of buildings is related to the physical structural form. If a building consists of two or multiple towers and a shared-base, recognition can be low if the vegetation blocks the base floors. The towers of the building can confuse visual recognition of people as the two towers appear as two separate buildings from a medium or far viewing distance.

Demographic factors may also influence the recognizability of buildings and the result can be validated by a quantitative survey and future researches. In order to further explore how vegetation influences the recognizability of buildings; a Green Ratio approach is proposed to calculate the ratio of obstructed vegetation to the nearby building.

As more "green" cities are emerging in the 21st century (The World Economic Forum, 2018), human recognition of urban buildings can be obstructed by increasing amount of vegetation in urban areas. While the architectural designs of urban buildings are more complicated than before, architects often seek the maximum exposure of the design to general public. The complexity of building structure actually captures inhabitant's attention (Heath et al. 2000). If vegetation obstructs significant portions of an innovative design of a building, the visual value and attractiveness of the building can diminish greatly. People may not able to retain much visual and spatial memories about a building or even a city because their views are obstructed. Eventually, the building loses its ability to covey the uniqueness to general public.

On the other hand, people choose to use a recognizable urban object or landmark to navigate (Lynch 1960; Appleyard 1969; Mark et al. 1999). Building obstruction by vegetation can significantly influence how people navigate among the concrete jungle. After all, it is essential to understand how buildings are recognized in a city to generate a better urban spatial configuration. Predicting visual recognition of buildings can bring benefits to urban designers, architects, city planners, landscapers, and city promoters.

Unfortunately, no existing studies have made attempts to explore the methods of predicting visual recognition of buildings in an urban environment. A considerable number of scholarly works devoted to visibility analysis (Bartie et al. 2011; Yin et al. 2012; Fisher et al. 1997), as yet no research the author is aware of has addressed visual recognition or recognizability of urban buildings from the perspective of geospatial information science.

The approaches developed in this paper serve the purpose of investigating spatial relationships between recognizability of urban buildings, distance, vegetation, and socio-demographic factors from a spatial perspective. The results presented here provide a starting point for further research in the development of a more sophisticated GIS model to predict and map the recognizability of spatial objects.

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Appendix

Table 1. Green Ratio of each photo

	BF Place close	BF Place mid	BF Place far	River Terrace close	River Terrace mid	River Terrace far	Bryant close	Bryant mid	Bryant far
Obstructed greenery pixel counts	31307	38660	20403	16374	41111	86761	3751	42923	42956
Building pixel counts	336470	181654	158867	150211	78701	264938	152492	76427	197704
Green Ratio (%)	9.30	21.28	12.84	10.90	52.24	32.75	2.46	56.16	21.73

	CF Plaza close	CF Plaza mid	CF Plaza far	DPM close	DPM mid	DPM Far	Fitterman close	Fitterman mid	Fitterman far
Obstructed greenery pixel counts	74016	65227	0	0	26347	110732	0	43521	59214
Building pixel counts	286689	140391	253516	83143	75893	234339	187865	135397	117997
Green Ratio (%)	25.82	46.46	0.00	0.00	34.72	47.25	0.00	32.14	50.18

	Foley close	Foley Mid	Foley Far	Herald Tower close	Herald Tower mid	Herald Tower far	San Remo close	San Remo Mid	San Remo Far
Obstructed greenery pixel counts	71902	259199	34873	0	25341	70935	61753	71326	17957
Building pixel counts	1193965	1055915	112885	77829	58487	219613	162244	104772	56829
Green Ratio (%)	6.02	24.55	30.89	0.00	43.33	32.30	38.06	68.08	31.60

	UN close	UN Mid	UN far	Majestic Close	Majestic Mid	Majestic Far	PC Close	PC Mid	PC Far
Obstructed greenery pixel counts	10833	189103	70856	69423	57358	49934	387587	520905	442794
Building pixel counts	549816	420691	202083	379944	83913	79632	697691	767834	737486
Green Ratio (%)	1.97	44.95	35.06	18.27	68.35	62.71	55.55	67.84	60.04

Map 1. Locations of target buildings