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Measuring the physical profile and use of Park Connector Network in Singapore with machine learning

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Abstract: Park Connector Network is a system of greenways strategically planned to link parks and open spaces across the entire Singapore. It functions both as nature corridors that effectively strengthen biodiversity and open spaces for people's everyday life that help to enhance community resilience and social sustainability. However, despite its crucial social significance, there are only limited knowledge about people's daily use of the greenways, and how they interact with the physical environment. This research aims to bridge this knowledge gap using cutting-edge machine learning technologies to measure, analyse and evaluate this relation. GoPro video survey and panoramic photo survey were conducted throughout the Park Connector Network to capture people's use and the physical profile of it, and which are then analysed using object detection model, Mark R-CNN and semantic segmentation model, PSPNet respectively. Finally, the results are correlated to each other using multiple regression analysis.

Keywords: urban greenway, machine learning, Park Connector Network, Singapore

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1. Introduction

One of the defining characters of Singapore is its flourishing vegetation and the high green coverage ratio and this also distinguishes the city-state from other cities that experience similar rapid urbanisation. Out of the elements that contribute to this unique feature, Park Connector Network is the key components. As part of a hierarchy of park system in Singapore, it refers to the multifunctional greenways that link parks, nature reserves, and open urban spaces in Singapore (Tan 2006). At the initial stage, Park Connector Network was regarded as s a tapestry of green throughout the island to provide corridors for the movement of bird and forming continuous habitat for wild life. With the continuous development of the city, Park Connector Network became recreational venues, places for socialisation and gathering, alternative transportation routes, as well as useful educational resource (Briffett et al. 2004, Tan 2006).

With regard of the relevant research on Park Connector Network, however, the main focus of majority of studies has long been and is still on the ecological perspective. Briffett et al. (2004) argued that the design of park connectors should include a combination of ecological and social research methodology to capture successfully the competing needs of human and wildlife. Nevertheless, while recreational and social values of greenways have been widely acknowledged and observed, current development of knowledge and methods of study on this aspect are inadequate for enabling informed design and development and without obtaining an appropriate understanding of social performance of Park Connector Network, it is impossible to develop meaningful proposals that can address and reconcile the competing needs as well as aspirations of various users.

To address this knowledge gap, we developed a study that aims to use the cutting-edge machine learning technology to gain a more comprehensive understanding of how people use the Park Connector Network in their everyday life and how their locational choice of social and recreational activities are related to and affected by the immediate environment. Currently, we are right in the middle of this project. What will be presented in this paper are the research design, in particular the detailed methodological approach, and some preliminary results. We hope this would provide readers with an overview of the project as well as its potential contributions to both the understanding and the design and planning of Park Connector Network.

2. Existing Studies and knowledge gaps

Urban greenways as linear networks of protected lands within the city have multiple functions such as nature protection, biodiversity management, water resources, recreation and leisure, and cultural/historic resource protection (Ahern 1995). Throughout its short history, landscape architects and urban planners have always found peculiar significances of greenways as answers to many problems rising from continuous urbanisation. The functions of urban greenways have been ever evolving. From relevant literature (see Fabos 1995, Nelson and Dughi 1994, Searn 1995, and Markeson 2007, just to name a few), contributions of urban greenways can be summarised into the following five categories:

Environment: Greenways provide more vegetation that helps to control air and noise pollution and also minimise water pollution through its pervious surfaces. It also helps to adjust the microclimate of urban neighbourhoods and hence provide good living environment for the wildlife away from the urban hassle.

Economy: Landlords can enjoy the increased property values and marketability of the properties and decreased expenses on outdoor recreation because of the proximity to greenways. Increased recreation in the vicinity provokes the involvement of small and local businesses along the greenways.

Health: Greenways provide linear non-motorized, pollution free, healthy environment to urban dwellers. It facilitates physical activities and also helps to improve mental health through physical activity and visual access to greenery.

Education: Greenways impart knowledge about existing surrounding flora and fauna. In some occasions, they can serve as living laboratories for people to learn about historic, archaeological, and cultural resources.

Aesthetic: Greenways significantly enhance the aesthetic values and quality of life. With the proven significance of greenways economically, the economists have attempted to place economic values majorly on the aesthetics and visual quality of the landscape.

The above literature on the multi-functions of greenways in the urban settlements brings forth two knowledge gaps. First, most studies place a great emphasis on the physical profile of urban greenways with respect to the claimed benefits, rather than studying in detail how the physical characteristics relate to and interact with the users. This was pointed out by Searns (1995) that the planning and design of urban greenways historically have been related to its physical profile as an answer to the rapidly urbanising world. And even in their study on the human dimensions of urban greenways, Gobster and Westphal (2004) summarised their findings in a set of six dimensions, namely cleanliness, naturalness, aesthetics, safety, access, and appropriateness of the development. This also shows that the physical environment instead of the use of greenways remains as the key consideration. While it is important for understanding how the multiple benefits of urban greenways are related to their physical conditions, it is equally, if not more, crucial to gain the knowledge about whether and in which ways residents can enjoy the benefits, especially those of great social values, through their interactions with the physical environment. To achieve this, a sound methodological approach is needed.

This then leads to the second knowledge gap that the majority of existing studies were conducted primarily taking a qualitative rather than a quantitative approach. Despite the insights that studies taking such an approach have offered, and its values in informing the design and planning of urban greenways in many cities, a more accurate and objective understanding of the relation between the physical environment of urban greenways and people's uses is still lacking. For instance, we would be able to know following a qualitative approach that people often frequently use the greenways for jogging, walking, cycling, and walking their dog, and also that some may occasionally use the greenways as the place for skateboarding, doing tai chi, flying kites, playing model planes, etc. However, without a more systematically understanding the quantity of participants in different activities and the extent to which the intensity of different activities is related to different physical characteristics, we would be very limited and constrained in designing greenways that can potentially bring more benefits to the users.

In response to the above two gaps and relevant needs, the advancement of computing technology in dealing with big data in recent years provide new perspectives on systematically capturing how the built environment facilitates and constrains people's activities and how people perceive, experience and respond to specific urban settings. For instance, numerous kinds of information from various sources, such as mobile phones, GPS traces, Point Of Interest mapping, geo tagged photos etc., have been used to deepen our understanding of social and economic performance of built form in both spatial and temporal dimensions. And the new open data environment such as google street view helps us to quantify street greenery and analyse urban visual corridor. Recent efforts started to explore new approaches to objectively measuring not only those easily quantifiable characteristics of urban form but more importantly the elusive qualities of urban spaces that were previously impossible to capture in a quantitative fashion (e.g. Sharma 2010, 2015, Ewing and Clemente 2013).

These new computing technologies and data environment potentially offer us promising opportunities for obtaining accurate understandings of the social and recreational function of urban greenways through systematic and objective observation and assessment of people's interaction with the physical environment.

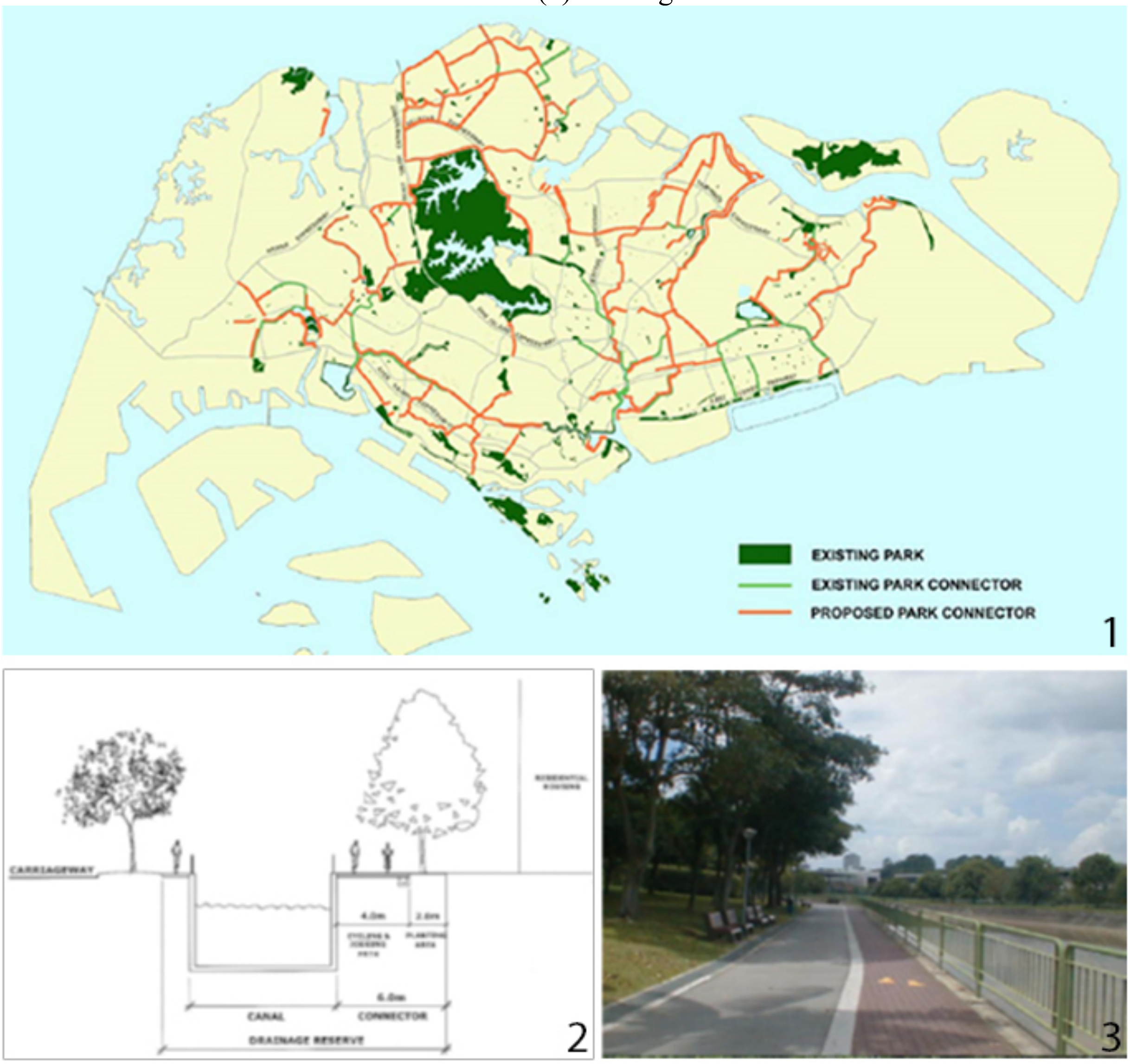
3. Park Connector Network

In the context of Singapore, Park Connector Network as a unique urban element of the city-state connects parks, nature reserves, open spaces, and different urban neighbourhoods. It plays an equally important role as that of streets in people's everyday life, both as an ecological network that is fundamentally important to wildlife and biodiversity and an open space for gathering, social interactions, physical exercises, leisure and recreational activities, and even transport.

Like greenways in many other cities, Part Connector Network evolved from a natural linear system at an early stage to both an ecological network and place for recreation and socialisation. The conceptualization, planning, and implementation of Park Connector Network in Singapore were traced in details by Briffett (2000) and Tan (2006). Park Connector Network proposal was approved by the Garden City Action Committee in 1991, and was subsequently included in the Green and Blue Plan drafted by the Urban Redevelopment Authority (URA). In this initial stage, it was described as a tapestry of green throughout the island to provide corridors for the movement of bird (Ministry of the Environment, 1993) and forming continuous habitat for wild life (Tan 2006). With the continuous development of new neighbourhoods, Park connectors became recreational venues, places for socialisation and gathering, alternative transportation routes, as well as useful educational resource (Briffett et al. 2004; Tan 2006). Plans for the greenway network were reinforced in the Concept Plan Review in 2001 (Urban Redevelopment Authority 2000, 2001) and more recently, in the Parks and Waterbodies Plan (Urban Redevelopment Authority 2002) shown in Figure 1. People generally use the park connectors for activities like jogging, walking, cycling, skateboarding, sight-seeing and walking the child or dog, and also for tai chi, flying kites, playing model planes, and even fishing.

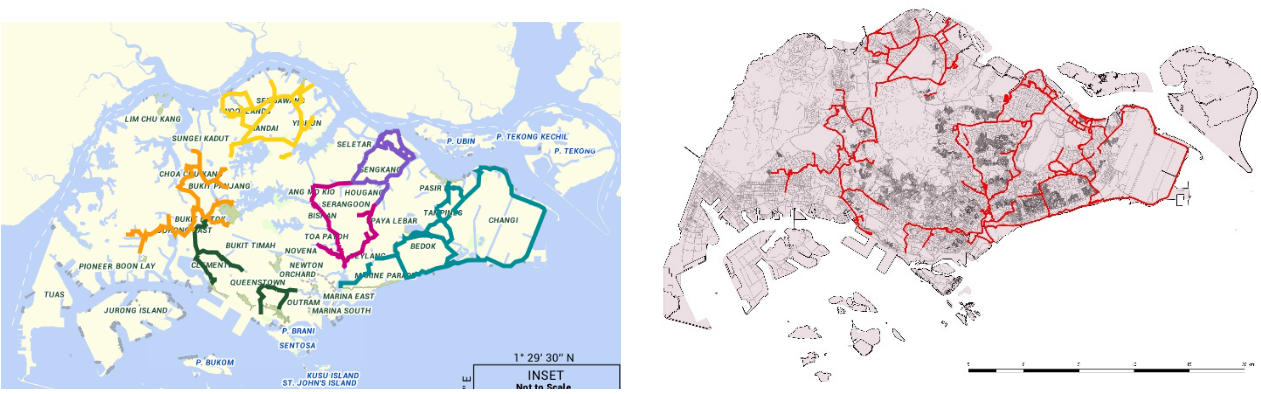
The left image of Figure 2 shows the existing Park Connector Network officially recognised by National Parks, a government agency that takes care of all green infrastructures of the city-state. Five loops located at different areas of the city can be clearly seen from the map. Apart from the existing 300 km Park Connector Network showed on the left side of Figure 2, there are a number of undocumented greenways distributed around the city that function in exactly the same way as Park Connector Network. To gain a comprehensive understanding of the physical profile and people's use of Park Connector Network in Singapore, we identified and documented those paths and incorporated them into the official map to produce our map of the 'entire' Park Connector Network for this study. This map is shown on the right of Figure 2.

Figure 1: (1) Existing and proposed Park Connector Network in Concept Plan - 2002 (2) Typical cross section of PCN (3) Kallang PCN



(Source: "A greenway network for Singapore" by Kiat Tan (2006))

Figure 2: Map showing official Park Connector Network (on left) and map showing added stretches to the existing PCN for the purpose of our study (on right)

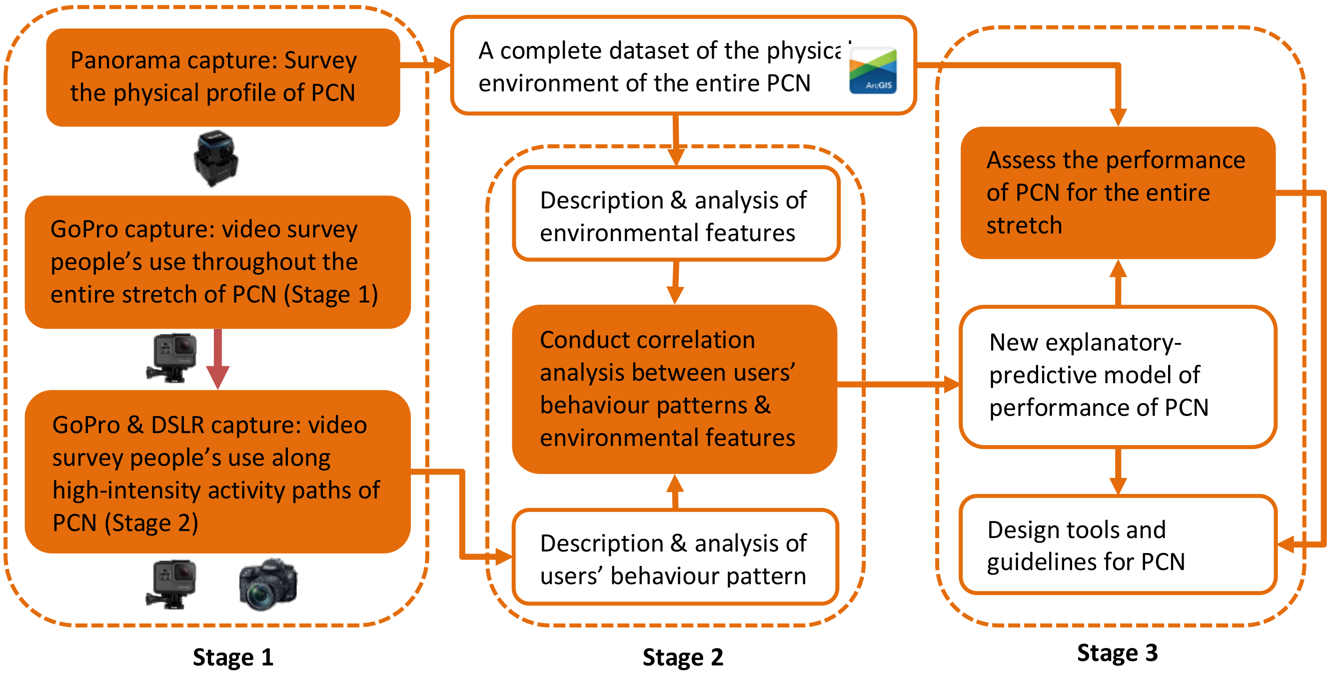


(Source: National Parks Board http://www.nparks.gov.sg (left) and map produced for the study (right))

With respect to future urban development, Park Connector Network is considered as a key strategy by the Singapore government to maintain park provision ratio, and address pressing challenges rising from increasing population and escalating land-use competition. It is proposed in the Land Use Plan 2013 (Ministry of National Development 2013) that the Park Connector network will be extended from around 300km at present to 360km by 2020. Given the planned increase by more than 20% in length in the next couple of year, obtaining an accurate and insightful understanding of profile and people's use of Park Connector Network and developing tools and methods that can inform decision-making in Park Connector Network design and development are therefore in dire need.

4. Research approach

Figure 3: Research approach



(Source: Authors)

The approach of this study is illustrated in Figure 3. The study will be conducted at three stages. First, a GoPro video survey and Panorama photo survey will be conducted throughout the entire Park Connector Network to collect data on people's use and the physical profile respectively. Second, the collected data from stage one will be processed using cutting-edge machine learning technologies to measure the intensity of activities at different locations and various components of the physical environment. Last, a detailed analysis of the relations between people's use and the physical characteristics of Park Connector Network will be performed on Arc GIS platform and, on this basis, a predictive model of the performance of Park Connector Network and guidelines for the design and planning of future Park Connector Network will be developed. As mentioned at the onset of this paper, we are now at stage two of this study, whereby data collected from both surveys are being processed and some preliminary results have been produced. In the following texts, we will present in details the research approach, especially the two types of surveys, before discussing some preliminary results.

4.1 Video survey of people's use of Park Connector Network

Data collection

The video survey is conducted in three stages.

Stage 1 aims to provide an overview of the distribution of users throughout the entire Park Connector Network at a relatively coarse-grained level. This requires an exhaustive travel along the full stretch of Park Connector Network to collect video footage using e-scooters mounted GoPro camera with GPS device. To gain an, as comprehensive as possible understanding, each segments of the Park Connector Network is surveyed at four different time slots, namely weekday and weekend morning and weekday and weekend afternoon. Only Tuesday, Wednesday and Thursday are classified under "weekday" while Saturdays and Sundays are both considered as "weekend". We exclude Monday and Friday because of the fact that people's daily routine in these two days are likely to be different from that of rest three days, and does not represent typical weekday. We also exclude public holidays for the same reason. We define "morning" as the period from 0700 hours to 1100 hours and "afternoon" as the period from 1600 hours to 2000 hours. We exclude lunch-time and the early afternoon due to low use of Park Connector Network, largely attributed to the tropical climate in Singapore, and also to address possible surveying fatigue from the heat.

Stage 2a aims to gain a more in-depth understanding of people's distribution, focusing mainly on those segments of Park Connector Network that are identified with higher concentration of uses, based on the survey result of the previous stage. Using the same camera settings and setup from stage 1, we repeatedly video scan each high-activity segment for 4 times with hourly interval for the morning session and 5 times with the same hourly interval for the afternoon session.. At the time of this writing, the data collection for this stage is still ongoing.

The goal of the third stage, which is regarded as stage 2b, is to understand at a fine-grained level the stationary activities taking place at various hotpots. The hotspots are identified based on the survey result of stage 2a as places where people usually stay for more than 10 minutes and become engaged in different kinds of social and recreational activities. For this stage, a DSLR camera is positioned at a vantage point in the hotspot zone to capture activities taking place throughout a weekday and a weekend day. The footage can then be processed with activity detection techniques for analysis.

Data compilation and analysis

In stage 1 of video survey, the objective is to capture human objects from the video footage, in order to understand the distributions of people's use of Park Connector Network. For this task, we employ Mask Regional Convolutional Neural Network (Mask R-CNN) to infer the frames contained within video footages. Mask R-CNN provides a framework for object instance segmentation and at the time of this writing, it is the state-of-the-art object detection model.

The Detection repository contains a Model Zoo of popular pre-trained models, amongst them is a Mask R-CNN pre-trained on the popular Common Objects in Context (COCO) 2014 dataset, which comprises 80 common object categories. This pre-trained model was chosen for the object detection task. The footages are organized according to the aforementioned four time slots, and it is then processed to extract the GPS path from the capture. The initial noise is treated and the remaining is visualized on the map. The retained captures then undergo inference by the pre-trained object detection model at the frame-level. Inference is only done on every fifth frame in sequence for the sake of efficiency.

After both the object detection and geo-referencing are done on a survey footage, an objects plot for the video is generated as Comma Separated Value (CSV) file. The file lists out geographical coordinates of every inferred frame and objects detected within it. This then allows the analytical results to be visualised with accurate geo-locations on Arc GIS, enabling an intuitive understanding of the distribution of people's use along Park Connector Network and then identification of segments with higher concentration of activities.

4.2 Survey of the physical profile

Data collection

For the panorama photo survey, the objective is to document the physical environment of the Park Connector Network and, more importantly, assess its environmental quality. For our capture setup, we used a tripod fixed at a ground-camera height of 1.5m (close to average eye-level) to support the iSTAR Fusion panoramic camera. The surveying procedure is simply to exhaustively traverse the entire Park Connector Network and capture panoramic shots at 15-20 meter intervals. To develop correspondence between panoramic survey captures with their respective locations, we attach a GlobalSat BU-353S4 GPS receiver to the iSTAR Fusion.

Data compilation and analysis

Each panoramic photo is analysed by gathering the extent of coverage for different physical elements such as greenery, foliage, sky, paths, etc., in order to understand the weight that different environmental features take at any specific location. For this task, semantic segmentation is used to provide the area coverage of various environmental features from an image. Pyramid Scene Parsing Network (PSPNet) is one of the state-of-the-art frameworks for scene parsing and ADE20K is the most challenging and well-annotated dataset for scene parsing with a diverse range of scenes and object categories. The model can detect an extensive 150 list of objects, but we re-categorized them by grouping some categories together according to our needs.

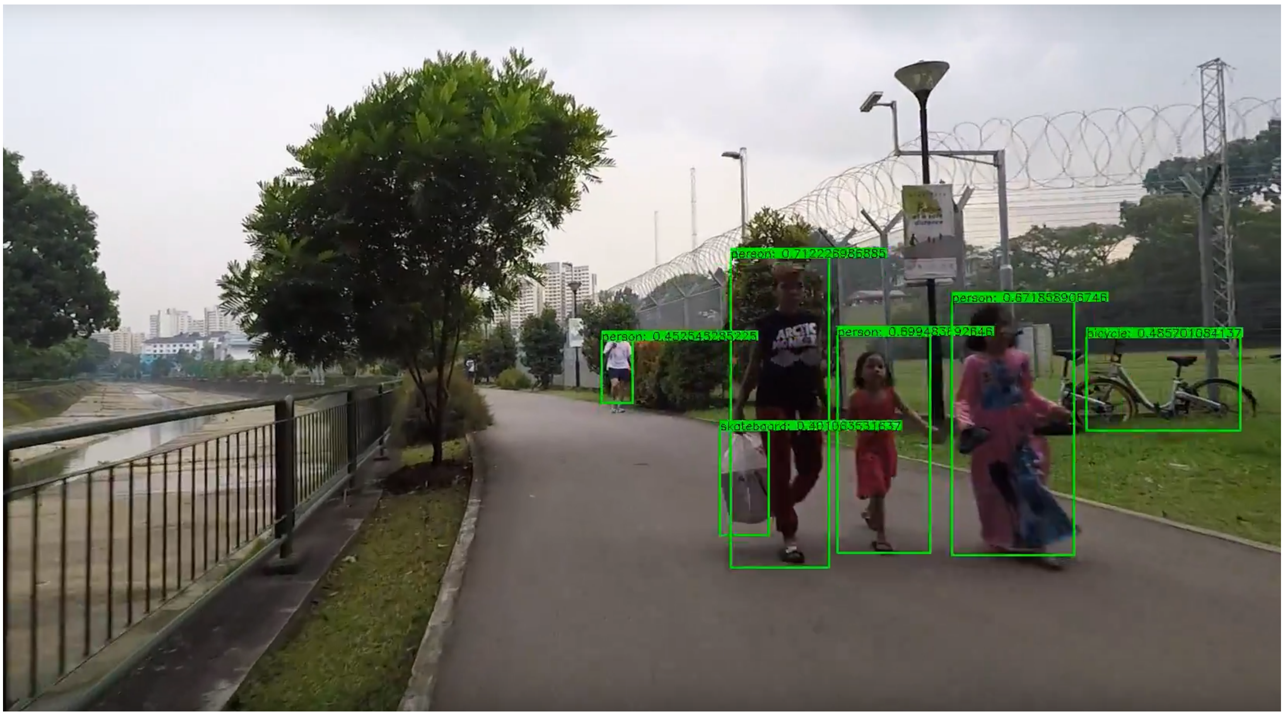
The panorama for the iSTAR capture is stitched together using NCTech's Immersive Studio software. In the process, it also outputs the panorama in cubic format where six cube-faces that make up the entire panoramic sphere, can be obtained. The entire stitched panorama contains warping distortions, which are not ideal for analysis, and therefore the model inference is carried out on each of the cube faces. After all the panoramas have underwent model inference, a segmentation plot is generated. The total area coverage in the scene for a semantic class is calculated by the total pixel coverage of the semantic class across all six cube-faces divided by the total pixels of all 6 cube-faces. Each segmentation plot contains unique geo-coordinates and, similar to the abovementioned video survey analysis, this allows the results to be intuitively visualised on ArcGIS for geo-spatial analysis.

5. Results

5.1. Distribution of users

As described before, at the time of writing this article, we just barely completed the first stage of GoPro video survey. The aim for this stage is to gain an overview of the user distribution throughout the entire Park Connector Network. We will present below a sample of video frame to illustrate how the Mask R-CNN object detection technique was applied for capturing people and other objects before discussing the overall distribution of users.

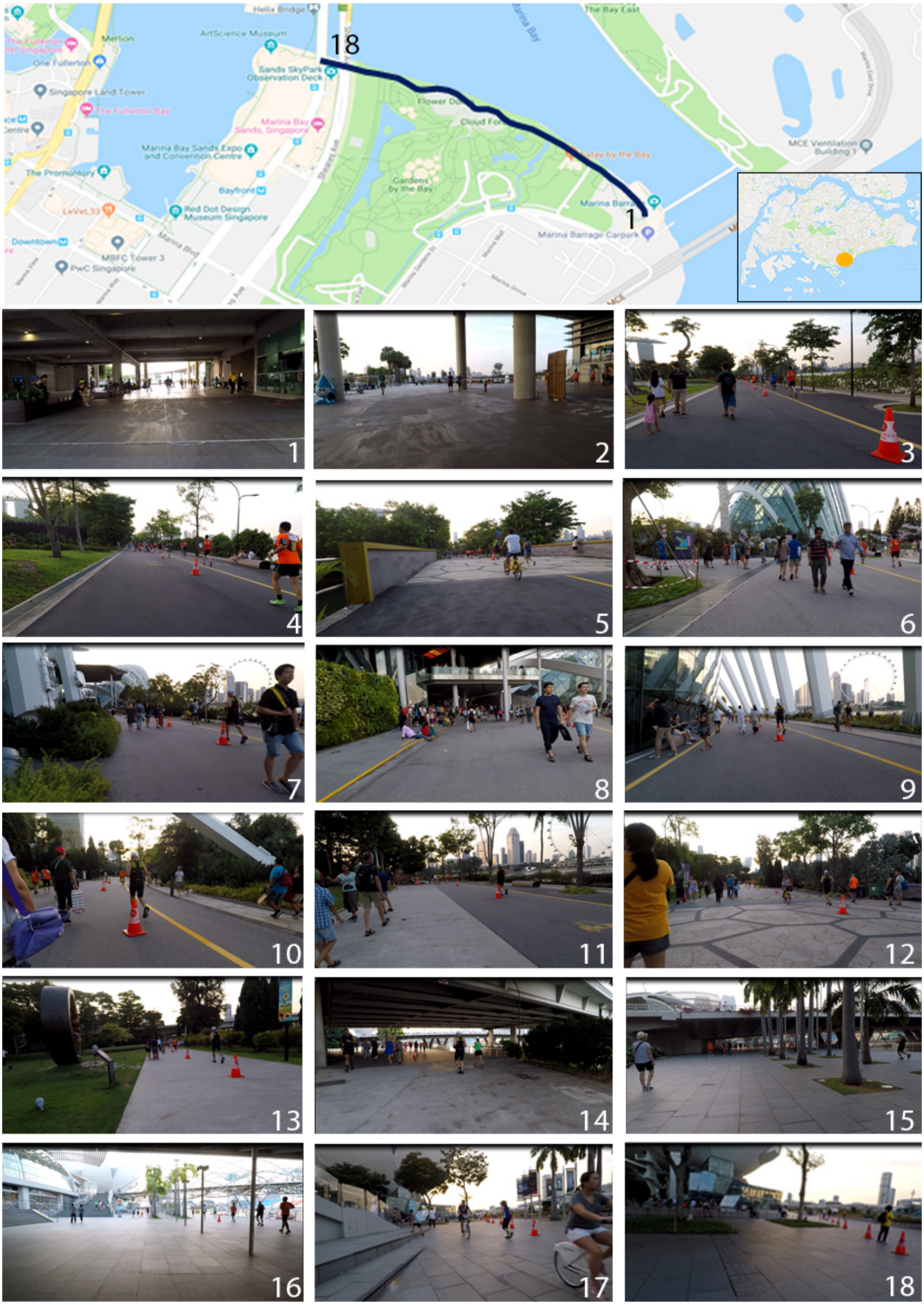
Figure 4: Illustration of object detection technique used for video data analysis



(Source: Authors)

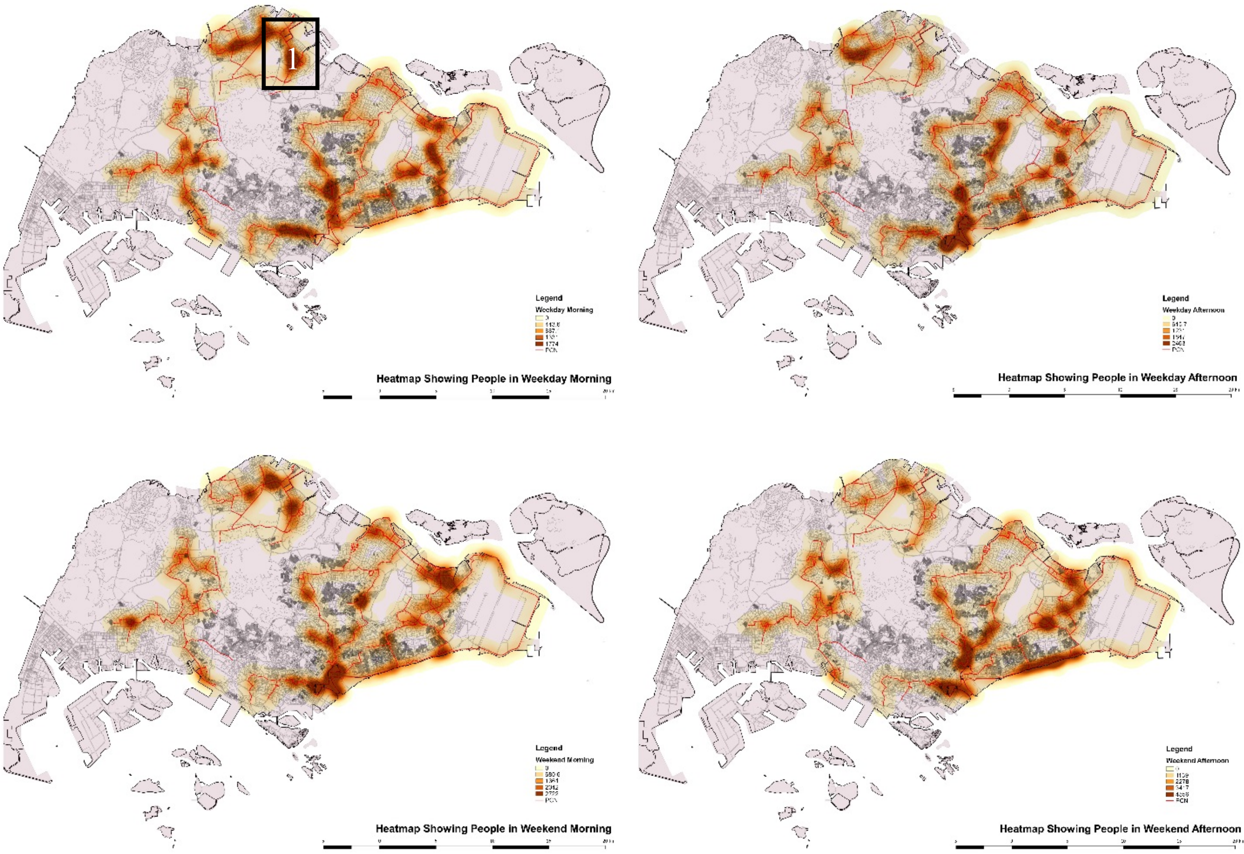
Figure 4 is a sample video frame showing that individual people are accurate recognised and detected. It is also not difficult to find that a range of other objects such as bags, bicycle, etc. are also clearly identified. The total number of people detected in a frame is registered as the people count for the corresponding location. Every single frame of the video survey data for the entire Park Connector Network is analysed to produce the distribution map of users for different survey slots. For demonstration, Figure 5 shows a segment of 1.3 kilometres in length along Gardens by the bay. The matrix of images below shows a sample of video frame in a sequence for weekend morning. The people count from each frame is registered and altogether describe the user distribution along the stretch.

Figure 5 Images showing PCN stretch along gardens by the bay on weekend morning



(Source: Google maps and Authors)

Figure 6: Heatmap showing pedestrian density along defined time slots



(Source: Authors)

Figure 6 shows the user distribution of along the Park Connector Network produced on ArcGIS platform for four different periods of time, namely weekday morning and afternoon and weekend morning and afternoon. The segments with high density of users are clearly seen in all maps. Most of these segments are captured accurately like the demonstrating example shown in Figure 5 where people appropriate the Park Connector Network for various social and recreational activities. These segments provide us with clear focuses for the second stage of the video survey to understand at a more fine-grained scale people's behaviour. However, since the Park Connector Network not only links parks and nature reserves but also residential area and public transport nodes, some segments shown in the map having considerably high density of users are in fact mainly attributed to high concentration of commuters. For instance, the segment highlighted in the weekday morning map, i.e. Point 1, is such segment, where commuters are detected either outside MRT station or at road junction (see Figure 7). No recreational or social activities can be identified from this segment. This segment will be excluded from the second stage of survey.

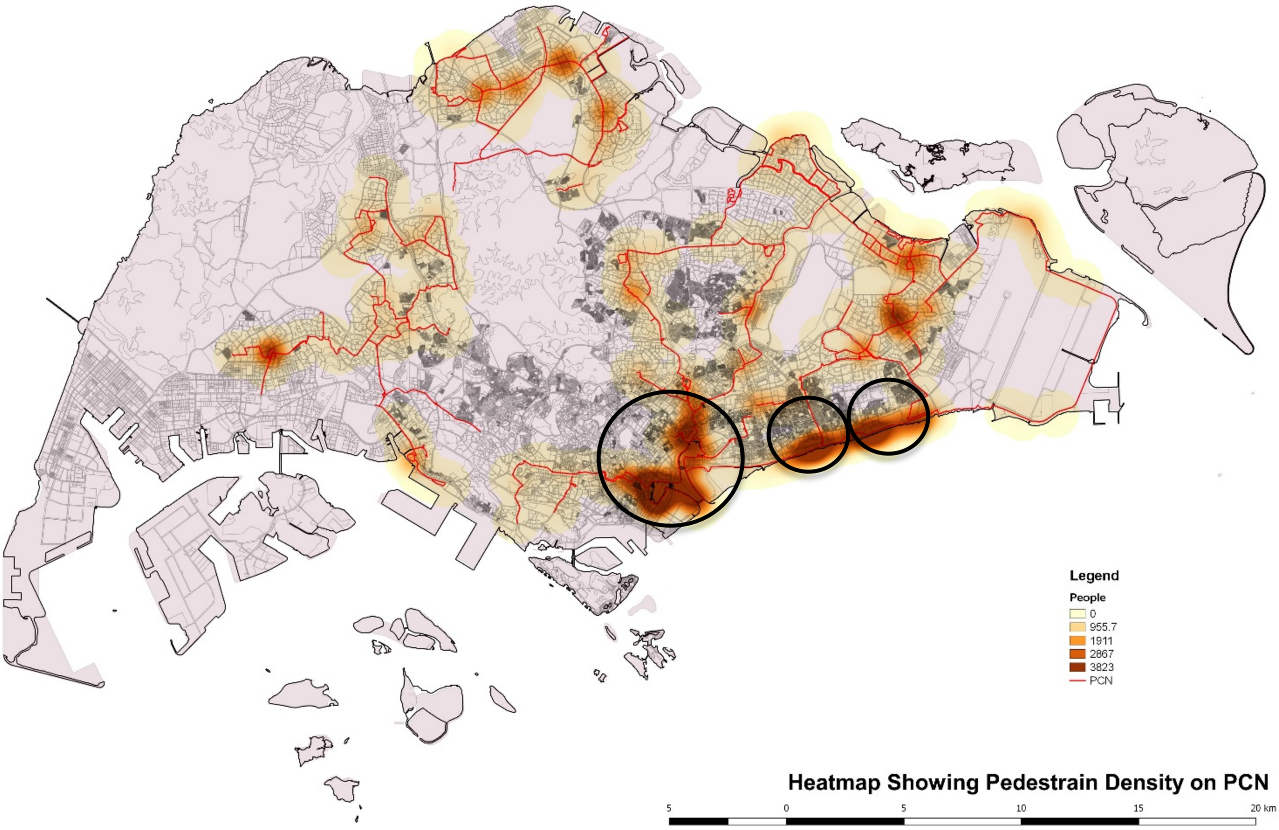
Figure 8 shows the aggregated user distribution along the entire Park Connector Network on Arc GIS platform excluding the above-described segments where there is a high concentration of commuters. It is very evident that there is a high concentration of users in the areas highlighted in the black circle, which means that these segments have user density across all different time slots. There are also a number of other segments showing reasonably high user density, though considerably lighter than those mentioned above. Nevertheless, located in the proximity to different residential neighbourhoods, those segments are generally where people appropriate for their everyday social and physical activities.

Therefore, those segments together with the evidently captured segments along the east coast of Singapore will form the focus for the second stage of video survey for a more detailed understanding of user's behaviour.

Figure 7: People outside Yishun MRT & road juntion (point 2)

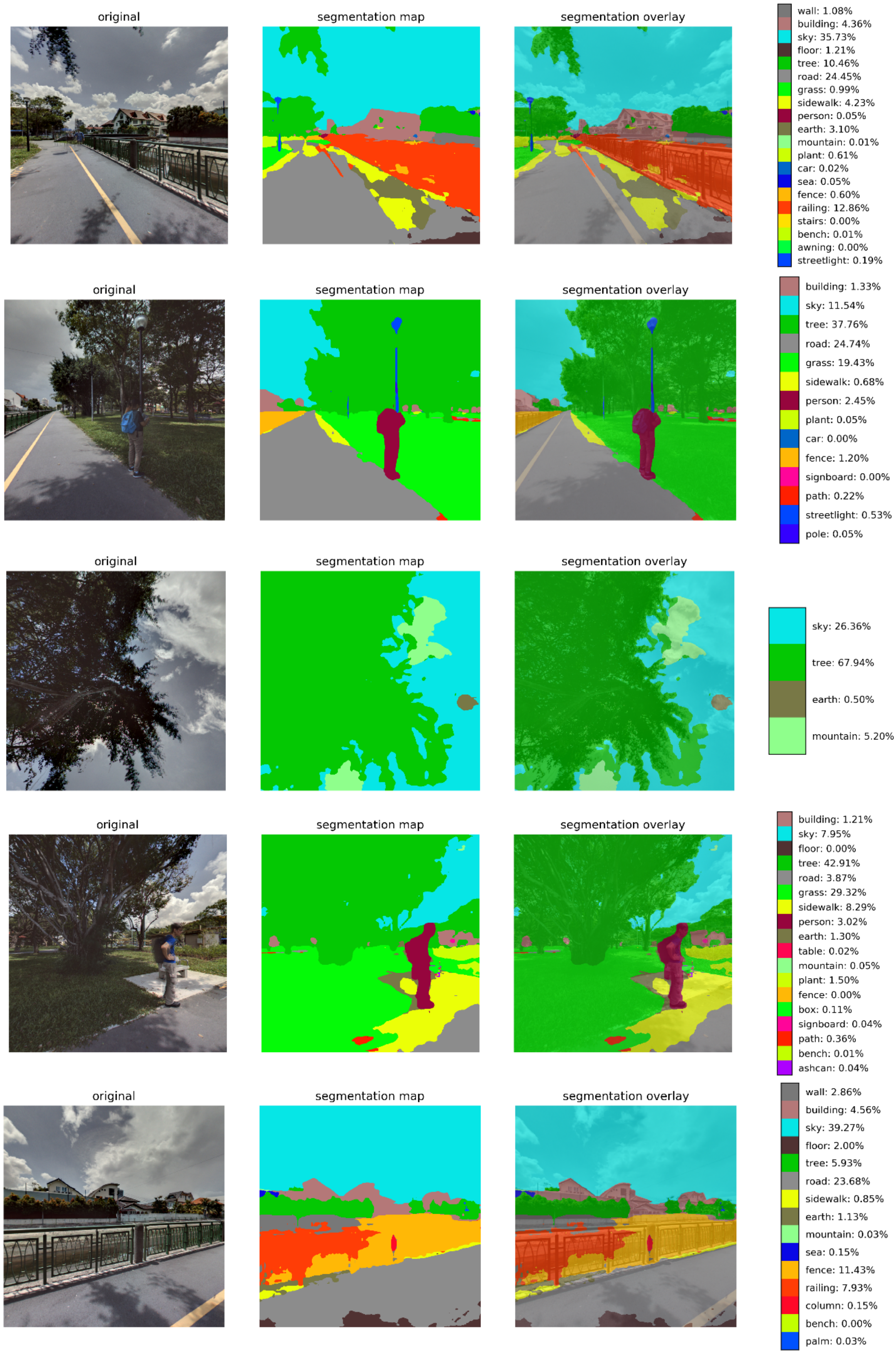
(Source: Authors)

Figure 8: Heatmap showing pedestrian density of entire PCN



(Source: Authors)

Figure 9: Results from the test for object detection using Pyramid Scene Parsing Network technique on panorama survey captures



(Source: Authors)

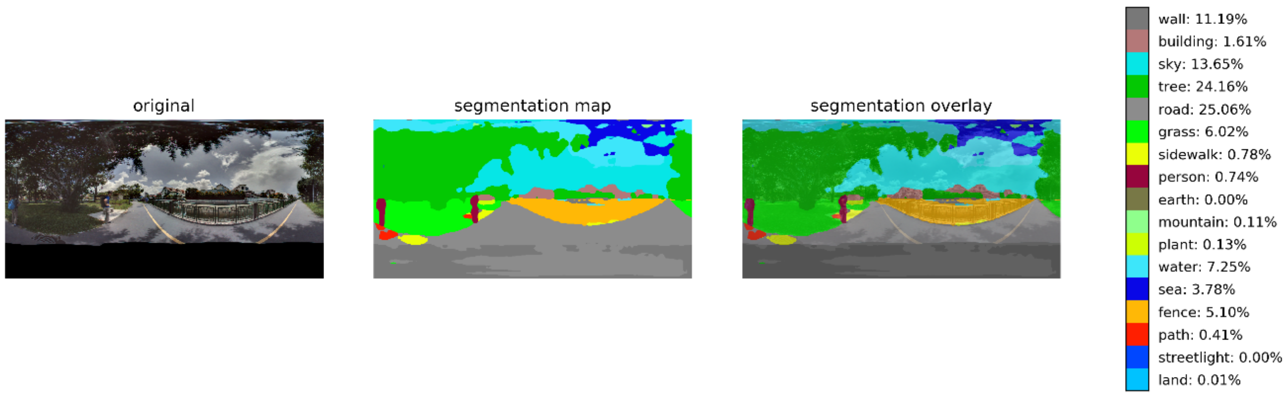
5.2 Environmental features

As explained before, a panoramic video survey was conducted in parallel with the GoPro video survey to capture and measure the physical profile of the Park Connector Network. And the aim is to assess the environmental features of the physical environment, and putting together with the results of video survey, to understand which environmental features are likely to exert more influences on people's locational choice of using the Park Connector Network. The results will be presented in two parts, namely segmented images and understanding environmental features for further exploration. Figure 9 above shows the results of the object detection on the cube faces from Panorama survey using the Pyramid Scene Parsing Network (PSPNet).

In the image processing, each panoramic photo contains warping distortions, which are not ideal for analysis, and the model inference is carried out on each of the cube faces that make up the entire panoramic sphere. Below is an example showing the result of model inference conducted on five cube faces from the panorama capture. The bottom image is not considered for the analysis purpose as it is a capture of the stage of the tripod used for survey.

The segmented images processed above using the PSPNet model can detect an extensive list of 150categories of objects. However, although the model is the most advanced one, it is after all not trained specifically for the purpose of this study. Hence, for the sake of our focused area of analysis we re-categorise the objects in a broader aspect for the desired results. The details can be seen in the images of Figure 10. The six cube-face images are stitched for the final panoramic presentation using NC Tech immersive studio as shown below in Figure 10, which provides an illustration of the overall environmental quality of the point surveyed.

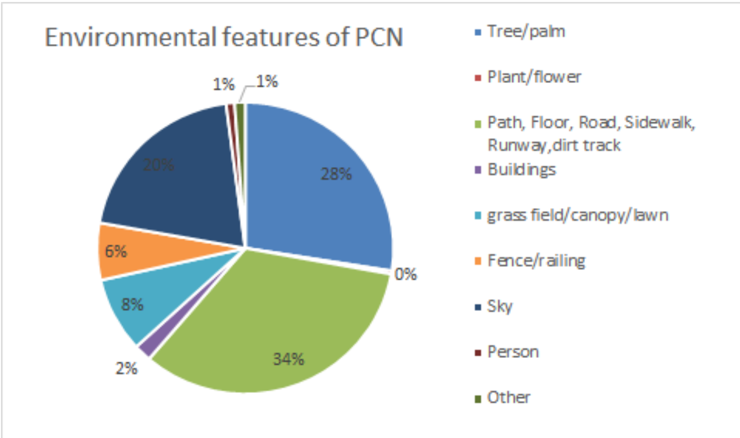
Figure 10: The final stitched panorama capture using NC Tech immersive studio



(Source: Authors)

The second part of the result is an aggregated calculation of the environmental features according to a set of broad categories for focused analysis. The aggregated calculation aims to gather the extent of coverage for greenery, foliage, sky, paths etc. in a given scene. Below is the test result from the above example which shows the extent of environmental features for that the point.

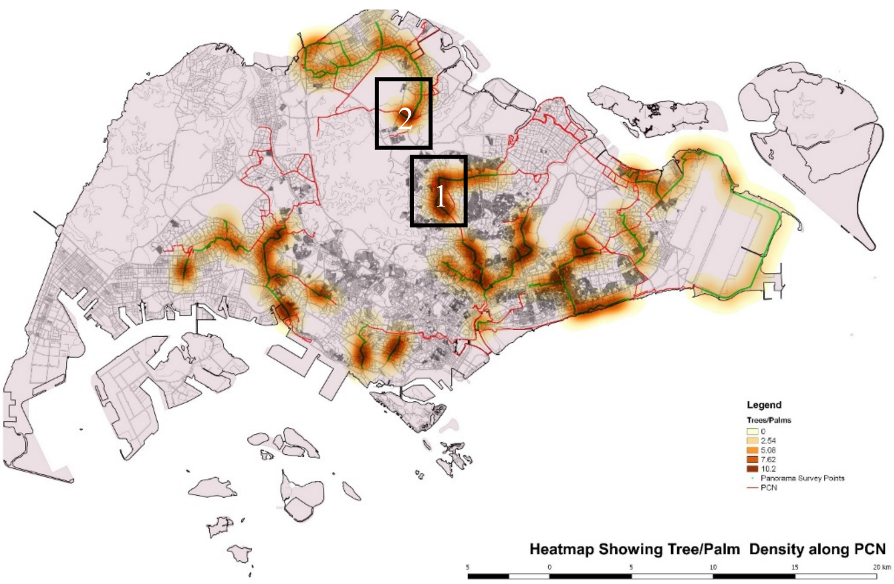
Figure 11: Bar chart showing the PCN's broader environmental features and its coverage



(Source: Authors)

From the above test result, there are three major categories contributing to the physical profile of the Park Connector Network, namely tree/palm, the carriageways and sky. It is hypothesised that components of the major categories are likely to contribute more to people's locational choice of their use of the Park Connector Network. However, since the panoramic photo survey has not been completed at the time of writing this article, we will only use an example to demonstrate who the results of the panoramic photo survey could be used for this purpose. For instance, let us consider concentration of trees in relation to user distribution drawn from the video survey. The point 1 in the tree density map below shows higher trees, and this is corresponding with the high density of users at the same geographical location shown in Figure 8, whereas for the location designated as point 2, the density of trees and users do not match with each other. We can then conjecture from here that the tree may play a major role in attracting users but other factors can also exert considerable influences on people's locational choice. This certainly requires studies at the next stage to clarify the correlations.

Figure 12: Heatmap showing Tree/palm density along PCN



(Source: Authors)

6. Conclusions

Park Connector Network as a key contributor to the Garden City of Singapore plays an increasingly important role in its residents' everyday social and recreational life in addition to an ecological corridor for biodiversity and environmental sustainability. Nevertheless, current development of knowledge and methods for studying this aspect are inadequate to enable informed design and development. A key issue is that most existing studies place a great emphasis solely on its physical profile, rather than studying in details how the physical characteristics relate to and interact with the users. This study attempts to bridge this gap by exploring how the cutting-edge machine learning technological of image segmentation and object detection can help to provide an accurate and comprehensive description and analysis of how people use the Park Connector Network in their everyday life and how their uses and locational choice are affected by the environmental features of the immediate surroundings. It is hoped that the results can provide new insights to inform the design and development of Park Connector Network in the future.

At present, we just barely completed data collection and conducted some preliminary analysis. Therefore, what we can present in this article is more about the research design, in particular the detailed methodological approach, and unfortunately only some preliminary results. However, despite the absence of the main results, we do hope this article could provide readers with a clear picture of the project as well as its potential contributions to both the understanding and the design and planning of Park Connector Network.

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Conflict of Interest

The authors declare no conflict of interest

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