Assessing the morphological distribution of urban green spaces for the future sustainable greenery planning: a case study of Penang, Malaysia

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Abstract

Urban green spaces are among the resources that provide many social and physical effects to decrease the adverse effects of urbanization. Their inappropriate locations can make them less accessible and, therefore, less sustainable or underutilized. This study presents the citywide and local characteristics of the size and morphological distribution of urban green spaces in Penang Island, Malaysia, using the space syntax method. Space syntax analyses were used to identify if there is a rational pattern for urban green spaces' size and accessibility and to determine the spatial distribution of needs and accessibility. To this aim, physical measurements of 24 parks and green recreational centers were calculated, followed by an axial mapping of the study area which was conducted to perform space syntax analysis. The results first showed that the locations of the green spaces were not equitably distributed, and larger green spaces were established in areas with less accessibility. Second, based on space syntax data, we evaluated the flood risk, land surface temperature, and population density maps. Finally, we proposed potential sites for future green spaces. This paper demonstrates new insights into the consideration for spatial priorities to reshape future urban green space planning in delivering more sustainable greenery.

Keywords Urban parks · Space syntax analysis · Superposition · Sustainability · Accessibility

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1 Introduction

The deterioration of the ecological environment globally has led to significant problems for human settlements since the twentieth century. Given the rise in the population due to the fast urbanisation and development of urban lands, the conflict between human activities and the natural environment has dramatically increased. In this sense, one of the worldwide important sustainability challenges based on the UN's Sustainable Development Goals (Goal 11.7) is to ensure global access to inclusive, safe and accessible green and public spaces (UN General Assembly, 2015).

Accessibility is one of the significant factors influencing the frequent use of urban green spaces, providing numerous benefits for retaining the natural and built environment (Ståhle, 2010). Hence, the location of green space areas should be analysed to know if they are optimally accessible and approachable. Concerning the necessity of green space presence in urban landscapes, accessibility to urban parks and green space has drawn the researchers' attention significantly. For instance, Lotfi and Koohsari (2009) tried to develop a framework for objectively assessing urban green spaces accessibility using the Geographic Information System (GIS) and fuzzy logic. Although some studies clearly distinguished between the presence (availability) of urban green spaces and their accessibility (Kabisch et al., 2016), these terms continue to be used ambiguously (Biernacka & Kronenberg, 2018; Schipperijn et al., 2017). Furthermore, urban green spaces accessibility has been measured by considering features, such as walking and public transport measurements to quantify the accessibility (Fan et al., 2017), physical amount of green space (Gupta et al., 2016), the amount of greenness that can be seen visually from a particular location (Labib et al., 2020) and safety (Niţă et al., 2018). In a review of methods, Maroko et al. (2009) mentioned three major approaches to assessing urban green spaces accessibility. Firstly, the container approach measures access by the quantity or the total acreage of parks located within a particular geographic boundary. Then, the walkability distance approach measures access by set distances between parks and the kernel density estimation approach that examine the accessibility value of a reference location by summarising the values of the distances from all spots of the study area to that reference location.

Since the early twentieth century, planning and determining the size and location of urban green spaces has been a challenge for urban planners and local governments. In the field of urban green space planning, the biggest concern is to manage the challenge of providing urban green spaces for public use and maintaining the sustainability of urban ecosystems (Afriyanie et al., 2018; Niemelä, 2014). Appraisal systems for the sustainability of urban development usually lack the indicators of urban spatial construction, leading to limitations on urban spatial development evaluations (Yu et al., 2020). Limited knowledge of ecosystem dynamics and the urban dwellers' needs and behaviour affect scale mismatches in managing urban green spaces and may consequently lead to the degradation of urban ecosystems (Afriyanie et al., 2020). Therefore, this event will result in inequalities in the spatial distribution of urban green spaces and affect urban resiliency and sustainability. In this sense, by superposing the various maps and analysis of urban networks, the optimal distribution of urban green space can be acquired (Jang et al., 2020; Jeong et al., 2021).

Furthermore, urban green spaces, and particularly urban trees, are vital elements of urban ecosystems. Apart from their aesthetic values, they contain habitats for many flora and fauna species, help avoid soil erosion by decreasing water runoff, control the urban heat island effect and improve air quality by absorbing air pollutants and emissions (Miller et al., 2015). The rapid urbanisation process enlarges the range of urban areas, increases

buildings' density, and changes the features of underlying surfaces. The temperature in urban areas is higher than that in suburban areas because artificial shells have a smaller thermal capacity than natural ones (Du et al., 2017). Urban green spaces can act as a comprehensive tool for the sustainable development of urban areas (Galeeva et al., 2014). As the benefits of urban green spaces are increasingly acknowledged, many large cities have undertaken sizeable urban greening programmes, including planting trees and expanding parks.

Malaysia is a developing country with rapid urbanisation, and Penang, one of Malaysia's most developed states, has recently experienced significant urban development. In addition, urban sprawl in Penang has led to heavy reliance on private vehicles, including longer commutes, congestion and loss of valuable green spaces. Penang is also recognised to be very vulnerable to climate change. A combination of increased average temperature and flooding will affect the well-being of citizens and lead to financial losses (Inn, 2019). In light of these issues, Penang has created Penang Green Agenda 2030 (PGA2030) to define a sustainable development plan for urban greenery. One of its critical principles is to understand and assess optimal land use for natural resource conservation, sustainable urban growth and initiatives regarding urban green spaces that focus on cooling effects and mitigating flood risk. The task of managing transforming urban landscapes, particularly urban green spaces, to provide sufficient natural amenities for increasing urban populations is one of the critical challenges facing policymakers (Chen & Wang, 2013). Theoretically, the amount of urban green spaces in a city is jointly determined by the natural environment (e.g., temperature and precipitation) and socioeconomic factors (e.g., economic status, population density, land availability and greening planning and policies) (Richards et al., 2017).

Choosing unsuitable locations for public green spaces can make them less accessible to those they are considered to serve (Hillier, 2007). This case may lead to abandoned or underutilised spaces, and even an abused space may be potential for crime occurrence (Tannous et al., 2021). Despite the importance of urban green space in contemporary urban planning, studies on the morphological distribution of public urban green space are limited, and their accessibility to residents at different locations has remained unclear.

Based on the reviewed literature, in order to add more green spaces to the urban fabric or expand the existing ones, there should be a comprehensive analysis of existing green infrastructure in case of accessibility to find out the needs and potential locations for adding sustainable green spaces. This gap in the current literature calls for analysis and valuable tools to quantitatively assess the spatial configuration of public urban green spaces in the urban network to provide a scientific insight for future green space planning by policymakers. Our specific objectives are as follows: (i) assess and determine the accessibility of public green space based on measures of space syntax and (ii) identify areas with good access and with regard to flood risk and land surface temperature maps in the case study of Penang, Malaysia.

2 Methodology

2.1 Research strategy

The Penang Island metropolitan area was selected as the case study. Firstly, we conducted a concise literature review of urban green space planning using the space syntax concept

to identify the key indicators of green spaces' location analysis. Then, we calculated the physical measurements, including areas and service distances of 24 public parks and green recreational centres, according to their location. In the task of evaluating their degree of accessibility, we examined their values of integration and choice within the urban street structure using the axial analysis methodology of space syntax (Penn et al., 1998) through the average value of all of the outer edge streets providing access to them (Tannous et al., 2021). We also superposed their location in spatial analysis, flood risk, and land surface temperature maps. Taking the results of this analysis into account, we looked for the pattern that they revealed for the existing green spaces and how optimally they are distributed. Finally, the modelling and analysis in the previous stages feed the development of several urban planning recommendations for selecting appropriate locations for public green spaces.

2.2 Selection of green spaces

Penang is an island state off the northwest coast of Peninsular Malaysia and is one of the most developed Malaysian states (Refer to Appendix A for more details). Penang Island possesses a hot and rainy tropical climate, similar to any other part of Malaysia. However, its temperature is often higher than the mainland as it is an island. Penang is the second smallest state in Malaysia by landmass; however, it is the nation's highest population density state and has the lion's share of developed industrial zones after Kuala Lumpur (Tew et al., 2019). The high density of urban developments and population highlights the need for an accurate understanding and assessment of urban green spaces' location and optimal accessibility because the land supply is far too limited. A total of 24 public parks and green recreational centres were identified in Penang Island for analysis. In order to make a selection of sample parks, the incidental green spaces were excluded to focus on the official urban parks and promenades.

2.3 Calculating the size and service distance of each green space

Each of the selected spaces has been initially categorised based on Town and Country Planning Department Peninsular Malaysia (2006) into the following size parameters: (1) playing lots ranging from 0.2 to 0.6 ha in size, (2) local play areas ranging from 0.6 to 2 hectares in size, (3) neighbourhood parks ranging from 2 to 8 hectares, (4) local parks ranging from 8 to 40 hectares and (5) urban from 40 to 100 hectares (Table 1).

Table 1 Initial categorisation of Penang urban green spaces

	Hierarchy	Number	Size (ha.)	Service distance
1	Playing lot	6	0.2–0.6	Within 0.5 km
2	Local play area	9	0.6–2	Within 1 km
3	Neighbourhood	5	2–8	Within 1.5 km
4	Local	2	8–40	Within 3 km
5	Urban	2	40–100	Within 5 km
	Total	24		

Figure 1 presents the overall pattern and distribution of green areas, including indicating the degree of environmental proportion. More details of Penang urban green spaces regarding their regions are presented in Appendix B.

2.4 Morphological analysis of green spaces distribution

Very few quantitative studies regarded urban green space accessibility based on morphological analysis (Bahrini et al., 2017; Ma, 2020; Tannous et al., 2021) mostly conducted in an arid climate. Accessibility derives from a city's configuration of the spatial layout and is interdependent with land-use patterns (van Nes & Yamu, 2020). In this sense, the space syntax gives quantitative data for multiple levels of accessibility in the urban spatial network. Space syntax methods can quantify the accessibility of urban green spaces based on the theory of Natural Movement coined by Hillier et al. (1993). This theory indicates that movement patterns in street segments naturally stem from how the road network arranges the shortest paths to and from all locations with the minimum changes of direction in the network before accounting for the place of attractors or creators of that movement. After
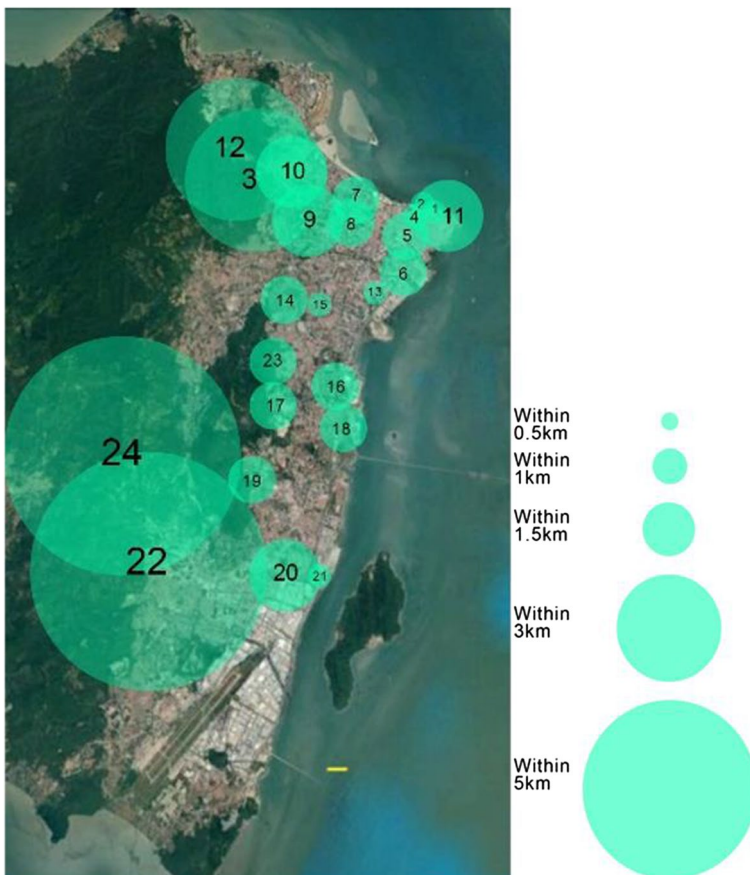

Fig. 1 Service distance map of the 24 selected urban green spaces in Penang Island

translating the network routes into a graph (that identifies the topological relationships between lines), the analysis of the system with quantitative parameters initiates by calculating how connected each of the spaces is with the other spaces in the network (Karimi, 2012). Hillier (1984) developed the concept of space syntax for analysing the street network structure through a set of spatial descriptors. This approach includes a set of theories and methods for modelling and analysing cities, using space as the fundamental generator of the city. These descriptors are calculated by the notion of "Axial map" (Koohsari et al., 2014). An axial map encompasses the longest, fewest and most strategic visibility lines for representing individual linear spaces in urban environments (Liu & Jiang, 2012). In order to analyse the Penang Island urban structure, an axial map was drawn using AutoCAD 2019 software and imported into DepthmapX software (Version 0.6.0) to calculate Integration and Choice values at the two radii: Rn and R3 (Appendix C represents more details on space syntax measurements).

Finally, an average of each measurement was obtained for the surrounding roads accessing and defining the boundary of each green space. Moreover, their metric area and space syntax measures were controlled to know whether the green space is too large or small for its relevant level of accessibility in the urban spatial network. As larger parks are likely to be more accessible in the urban network due to a merely larger size, this might be beneficial for design and planning purposes, particularly denning spaces that might be potential for future green space augmentation.

2.5 Superposition of obtained maps

Green spaces should assist in equilibrating the land surface temperature and sponge approach for flood probability. To this end, accessibility assessment by space syntax analysis maps was then superposed to the existing land-surface temperature and flood risk maps. This technique is an approach that includes the different characteristics of the study area and makes comparison possible (El Maguiri et al., 2016). The method allowed us to consider the accessibility value of the existing green spaces and reveal potential areas for future parks and green recreational centres according to Penang Green Agenda 2030 for future needs of green spaces.

3 Case study

3.1 Space syntax values of the selected green spaces

For this study, a total of 10,592 axial lines were drawn and analysed for the spaces syntax model of the Penang Island metropolitan area as the case study to obtain the space syntax measures. The location of the 24 selected green spaces was plotted, and the average syntactical values for each were calculated. As expected, a number of urban parks are more integrated within the street network than others. The total area of these spaces is approximately 183 hectares, including six playing lots, nine local play areas, five neighbourhood parks, two local parks and two urban parks. Figure 2a shows that nearly a large part of the Penang Metropolitan area is covered by highly integrated areas at Rn or global level (i.e., red to orange lines) and that the least integrated areas (turquoise and blue) lie in the west and particularly in the north. Figure 2b shows the locations of the parks regarding the axial maps for each level of integration and choice values. Much of the large parks are expected to lie
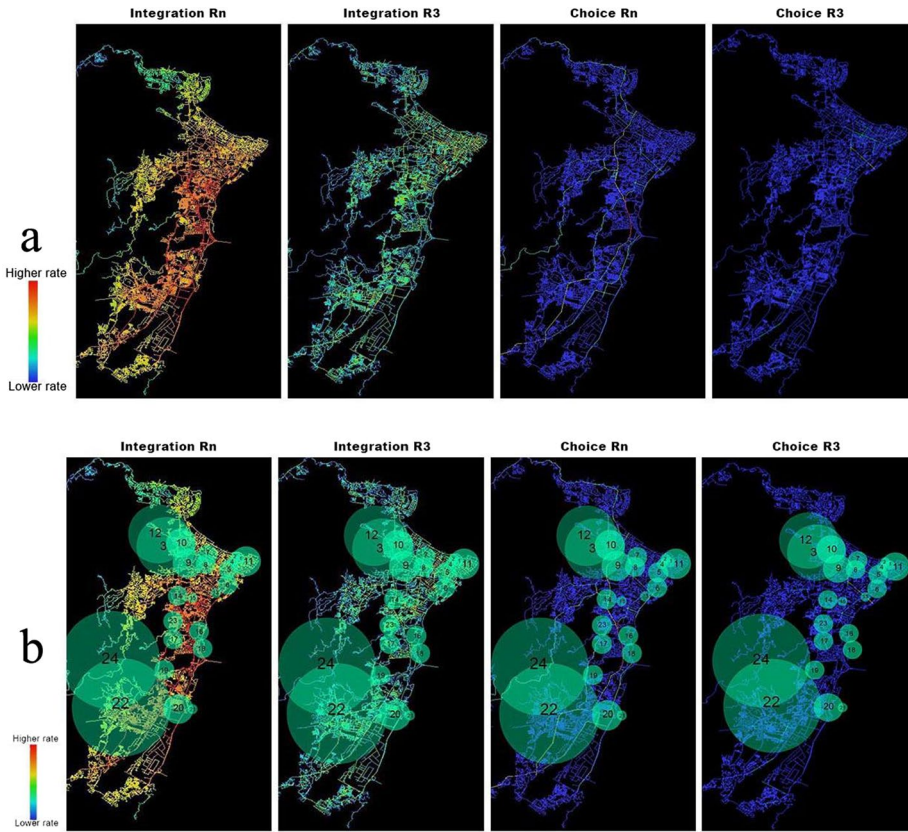
Fig. 2 **a** Axial map analysis of Metropolitan in Penang Island with streets colours ranging from red (highest rate) to blue (lowest rate), **b** Location of Penang Island Parks regarding the Space Syntax value maps with colours ranging from red (highest degree) to blue (lowest degree)

within this area because they are considered accessible from an extended part of the city as a whole. However, only two neighbourhood parks, Recreation Park Northern Region and Taman Sri Nibong Park, are located within the Rn highly integrated areas. The rest of the green spaces in this area are local play areas or smaller ones.

Moreover, in the global Choice (Rn) value map, as demonstrated in Fig. 2a, only four parks, namely, Recreation Park Northern Region, Penang Bicycle Park, Raffel Park and Island Glades Playground, lie within the area with a high choice value. Looking at local integration (R3), the pattern is different. The highly integrated areas are mostly located in the George Town region, the urban heritage of Penang Island. The other highly integrated areas appear as isolated grid patches across the city. Some highly integrated parks into the global radii are also apparently integrated into the local scale, such as Pekaka Park and Penang Bicycle Park. Moreover, others, such as Raffel Park and Armenian Park, remain as being accessible on local scale, which were not so on a global scale.

Thus, those parks located in highly integrated Rn areas should be more accessible and popular amongst the users. Figure 3a shows the area and global integration, indicating that the overall rate of the relationship between the green spaces area and their pertaining global integration is not logical in most cases. Moreover, the largest green spaces,
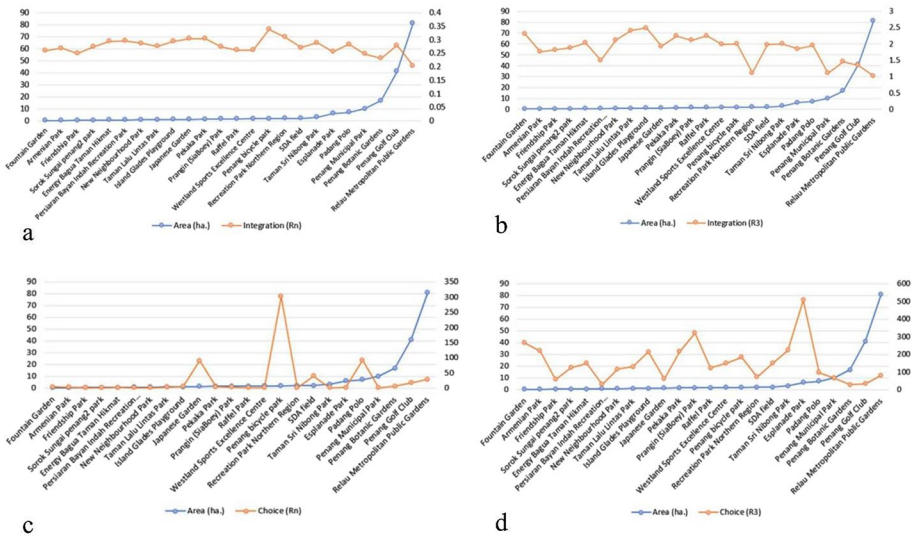
Fig. 3 Comparison of the selected green spaces area (ha.) and **a** global integration (Rn), **b** local integration (R3), **c** choice value (Rn), and **d** choice value (R3)

including Penang Golf Club and Relau Metropolitan Public Gardens, lie within the area with the lowest degree of global integration. Urban large parks are supposed to be the most accessible and ought to demonstrate popularity amongst the users. However, Penang Golf Club and Relau Metropolitan Public Gardens are less accessible than other green spaces to the entire metropolitan network.

Figure 3b shows the relation among selected green spaces area and their relevant local integration. In this sense, smaller green spaces are in areas with high local integration, such as Fountain Garden, Taman Lalu Lintas Park and Japanese Garden. This notion sounds logical because smaller parks and green spaces should be located in areas with higher local integration. However, also on this scale, larger parks, including Relau Metropolitan Public Gardens, Penang Golf Club and Penang Municipal Park, are amongst the areas with the lowest degree of integration R3.

Figure 3c demonstrates the relationship between the selected green spaces area and the choice value for each. Parks within the street segments having a higher degree of choice value tend to be more selected to be utilised by cyclists (Sharmin & Kamruzzaman, 2018), even if they have some aesthetic or maintenance problems. Therefore, large parks, such as Relau Metropolitan Public Gardens, Penang Golf Club and Penang Botanic Gardens, that are in areas with a low degree of choice might not be utilised even if they are greatly designed and decorated. The choice value is an important space syntax measure that can profoundly predict the rate of space, particularly green spaces utilisation, but is often overlooked.

Moreover, Fig. 3d depicts the relation of selected green space areas and their relevant local choice (R3). The local choice is an important measure and the strongest predictor for the presence of a pedestrian in the green space. Consequently, parks and green spaces with a smaller size can have a higher rate of local choice (R3), such as Fountain Garden, Prangin (SiaBoey) Park and Esplanade Park. Friendship Park, Persiaran Bayan Indah Recreation Park, Japanese Garden and Recreation Park Northern Region are within the areas

with a low rate of local choice. However, they are amongst the smaller areas. Finally, just as other space syntax measures, the local choice of the three largest green spaces, namely, Relau Metropolitan Public Gardens, Penang Golf Club and Penang Municipal Park, lies in the lowest rates. The relevant tables for space syntax measures are presented in detail in Appendix D.

Remarkably, for local green spaces less than one hectare, local integration seems to have a spatial logic, and these spaces have a majorly high rate of local integration. Conversely, their global integration is also at a high rate, which shows randomness in the placement of their location. Their choice degree (Rn) is also not surprising, and regarding the size of the area, they are amongst the lowest degrees. However, from 1 to 2 hectares, the global (Rn) and local (R3) integrations match their size and follow the spatial logic. The choice value for Japanese Garden and Penang Bicycle Park is surprising. Although both are of the local play area, they are located in the vicinity of two important highways, namely, Jalan Masjid Negeri and Dr. Lim Chong Eu, which have the highest potential to be utilised. Penang Bicycle Park also has a linear form, which would lead to being even more chosen than the Japanese Garden. From 2 to 10 hectares, the highest rate of randomness exists, indicating that the larger the size of green space is, the more accessibility measures are neglected.

The three largest green spaces, namely Penang Municipal Park, Penang Botanic Gardens and Penang Golf Club, were expected to have the highest rate of accessibility. However, compared to the other green spaces, they are not located in areas with the highest degree of integration, global in particular and choice because of the large size they ought to be accessed from all over the metropolitan area. They are not even amongst the most local integrated regions. However, this case could be explained because of the orientation of the Penang metropolitan growth that is adjacent to the massive lands covered by forests. In order to benefit from the natural green spaces resources, these large parks are on the edge of the metropolitan area and consequently have a low degree of accessibility. Refer to Appendix E for detailed information about the degree of accessibility for each urban green space from the smallest to the largest area.

3.2 Potential areas for additional green spaces

As discussed in previous sections, urban green spaces and particularly urban trees are a vital component of urban ecosystems. Sealed soil areas with a lack of green spaces lead to some damages as they may contribute to the urban heat island effect, increase the flood risk as they lead to surface runoff, and decrease rainwater infiltration (Morel et al., 2015). Temperature changes in a densely built-up urban environment are associated with the urban heat island phenomenon occurring in urban areas and distinguished by higher surface temperature. Urban green areas can decrease the urban heat island and consequently land surface temperature, particularly in the city core and industrial segments. These situations need to be controlled through comprehensive spatial planning and the design of urban areas in relation to the predicted climate change (Sobocká et al., 2021). In this sense, Penang Island is very vulnerable to climate change because of the increase in the average temperature, which is predicted to rise by 1.5 °C by 2030. Penang Island's highest degree of land is within the George Town area at the north-east of the Island, which is the urban heritage and touristic brand of the Island. Furthermore, Penang faces a flooding risk because of the increase in extreme rainfall. Therefore, a combination of increased temperature and flooding risk should be considered while planning for greening and adapting a sponge city model.

In this study, the identification of potential areas was realised by superposition of space syntax analysis maps, land-surface temperature and flood risk map of Penang Island. Superposition of the maps was conducted in Photoshop CC2019 software. The obtained results (Fig. 4) show that potential areas are mainly specified in intensive industrial, commercial and touristic regions. The most environmentally sensitive areas can be seen in the southern part of George Town, which has fewer urban green areas. Other situations are in Mukim 12 and 13, along with coastal line and Masjid Negeri and Sultan Azlan shah highways, which are pretty large areas allocated to dense residential, commercial and technology industries.

In the process of adding greenery to the urban fabric, green spaces and public parks are beyond their physical and aesthetic features for the users. Their accessibility to local neighbourhoods and the whole city based on their size can affect their use and consequently their lifetime. Nowadays, improving accessibility is one of the utmost design elements for urban green spaces, even more than adequate lighting, walkways and sports amenities because of the hectic lifestyle of urban dwellers. Figure 5 shows the location of potential areas, and Table 2 presents their pertaining space syntax measures for future green spaces in the Penang Metropolitan area. In addition to their duty, the accessibility factors are also considered based on natural movement theory and space syntax analysis to control urban heat and mitigate flood risk.

Moreover, based on the map of population distribution by density, B and D should have the highest area to cover the suitable catchment population. A and C come next in this sense, and finally, F, E and G have the smallest areas, respectively. As shown in Table 2, the existing green spaces and parks follow a logical pattern in terms of size. However, a remarkable lack of parks exists between four and six hectares in size. Therefore, the newly added green spaces would rather be around this area domain.
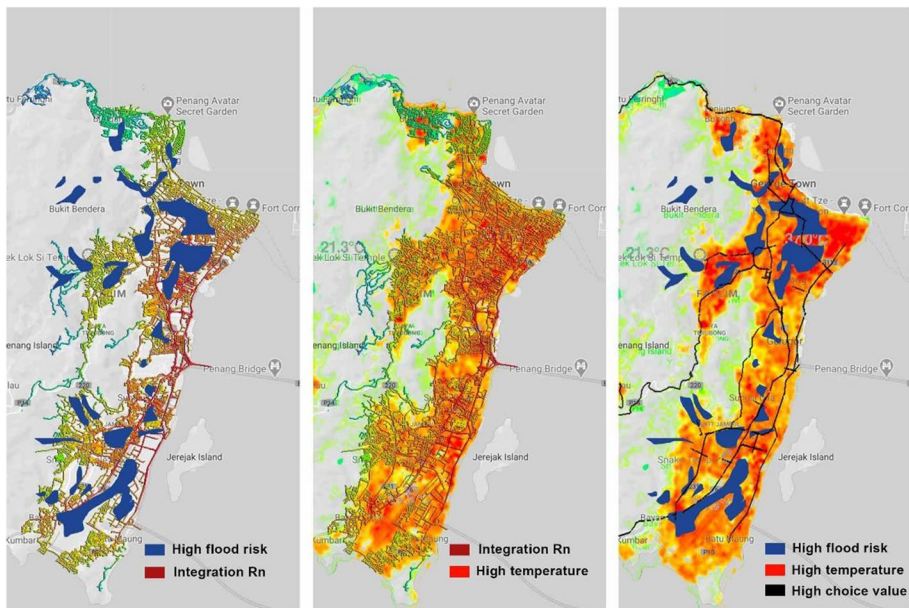

Fig. 4 Superposition of the space syntax maps (*source* the authors), land-surface temperature and flood risk maps [*source* The World Bank (2020)]
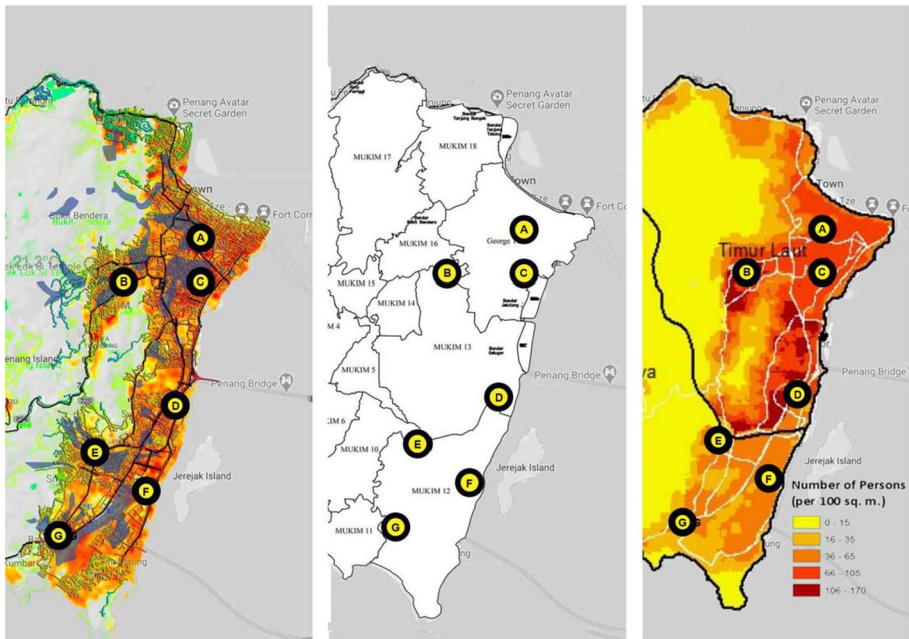
Fig. 5 Potential areas for additional green spaces

Table 2 Potential areas for future urban greenery and their space syntax measures

Potential area	Integration (Rn)	Integration (R3)	Choice (Rn)	Choice (R3)
A	0.296	3.322	$215.6*10^5$	2054.000
B	0.292	2.228	$140.9*10^5$	137.000
C	0.311	3.329	$345.2*10^5$	1288.000
D	0.312	2.085	$323.3*10^5$	146.000
E	0.299	2.480	$202.1*10^5$	397.000
F	0.329	2.173	$159.5*10^5$	380.000
G	0.305	2.554	$632.2*10^5$	1359.000
Total metropolitan average	0.265	1.415	$6.392*10^5$	33.211
Total metropolitan maximum	0.345	3.984	$651.659*10^5$	6384.000
Total metropolitan minimum	0.067	0.333	0.000	0.000

4 Discussion and conclusion

This study aims to analyse the distribution pattern of main green spaces in Penang Island, Malaysia, regarding their accessibility factors and further identify potential areas for planning any future urban greenery expansion. Urban green spaces can play a crucial role in encouraging an active lifestyle for urban dwellers, and accordingly reducing health risks such as overweight, obesity and poor mental health. Therefore, research into the links among green parks and their usage is essential for the renewal of human fitness (Liu et al., 2021; Zhang et al., 2015). It is widely argued that urban green spaces accessibility has been

a dominant design principle in the planning process of smart cities due to its grounding in the normative concerns of spatial equity, besides the ease with which it can be evaluated (Turaga et al., 2020).

This study was conducted using the theory of space syntax and superposition of the obtained maps. Space syntax has been widely employed by many studies regarding urban fabric functions and elements, such as squares, plazas, parks inside, or even regarding concepts, such as evaluating and analysing the quantitative measurements of accessibility (Tannous et al., 2021), wayfinding and also crime prevention (Askarizad & Safari, 2020; Summers & Johnson, 2017; Zabihi et al., 2021). Nevertheless, space syntax was not been employed as conducted in this study for assessing the relationship between volume and accessibility of urban green spaces and identifying the possible future areas to provide the optimal efficiency in terms of accessibility and climate change initiatives in a tropical urban fabric, in particular. Penang Island was an ideal case study because of the recent significant urban developments in line with Smart City plan; Penang is looking at its transformation into a smart state by 2030. Therefore, this study design is amongst the pioneers of this area and can be employed to conceptualize urban green spaces in the broader smart cities framework globally. This approach can help enhance people's presence and contribute to a more vital city by preventing the deterioration of urban green spaces.

The results of citywide analysis of Penang Island green spaces, parks and green recreational centres indicate a complicated image. The selected parks and green spaces belong to both Malaysia's post-independence or modern urban planning and New Urban Agenda (NUA) periods. However, in both periods, no unified pattern is found in the distribution of parks and green spaces concerning the city's spatial configuration. Governments should consider this issue to attach importance to city administration and build up an integrated plan of urban green spaces that benefits people and succeed in sustainable city branding and enhancing the city's future growth visions (Yang et al., 2019).

Furthermore, considering the number of green spaces and their size, evidently, many of the large parks and promenades, including Penang Botanic Gardens, Penang Golf Club, and Relau Metropolitan Public Gardens lie within the areas with the least accessibility on space syntax analysis maps. Conversely, small parks, including Japanese Garden, Sorok Sungai Penang2 Park and Energy Bagua Taman Hikmat seem so small for their substantial degree of accessibility from the city-wide scale to the neighbourhood scale in the urban spatial network. This issue might lead to the over-use of more accessible parks and degradation in environmental qualities of larger parks with less accessibility (Koohsari et al., 2015). However, this case would be fine if the small green spaces' local integration and choice (R3) are at high rates because these parks are planned for local neighbourhood dwellers and local accessibility will enhance their use fitness. This finding aligns with previous literature regarding the importance of green spaces accessibility for an active lifestyle and overall well-being (Liu et al., 2021; Zhang et al., 2015).

After superposition of the maps as mentioned earlier, the findings suggest that in line with Penang Green Agenda 2030, add more green spaces to the urban fabric of Penang, before adding new green spaces. The existing parks and green spaces, such as Prangin (SiaBoey) Park, New Neighbourhood Park, Sorok Sungai Penang2 Park and Japanese Garden, would rather be expanded because of the significant amount of land available near them. From another perspective, various informal and natural green spaces exist within the metropolitan area of Penang. These spaces are also in locations with acceptable levels of accessibility from the space syntax analysis that should be seriously taken into account by bringing them into the urban design plans for future greener Island. Many of the aforementioned parks and green spaces are considered as local and international tourist attractions,

thus the promotion of investments and developments are required to become one of the focal points of decision-makers and urban planners for city branding of Penang Island, allowing the city to have competitive advantages both regionally and internationally.

Further discussion is possible by adding blue spaces (i.e., outdoor environment featuring a layer of water) to the existing green spaces that may significantly lead to positive effects on urban land surface temperature (Sobocká et al., 2021). Finally, in addition to the high space syntax rate of accessibility, erecting more coastal parks around D & F spots in Fig. 5 can also be beneficial, given the land limitation of the Island. This study has shown that using available maps together with novel computer modelling to extract the numeric characteristics of the parks and green spaces can profoundly make it possible to understand their distribution pattern in an urban fabric, which is in line with the findings of Bahrini et al. (2017) study. Furthermore, this study could expand into other cities and metropolitans to examine the correlation of urban green spaces' location within the city spatial configuration and their actual usage according to their accessibility (Ma, 2020; Richards et al., 2017).

Urban green spaces with high accessibility are widely revealed to encourage exercise, social interactions and consequently the overall rate of health (Lindley et al., 2019). In addition to access, green spaces control environmental hazards, such as flood risk and land surface temperature, that lead to more sustainable urban growth. They can also improve the aesthetic values of a city. Therefore, urban green spaces are often advocated as a design element in sustainable urban planning. This study was conducted in an urban context with a tropical, hot and rainy climate. Urban green spaces have a significant role in temperature moderating and soil erosion to prevent local floods.

In particular, the study extends the discussion more than just a one-dimensional approach, which simply calls for a quantitative increase and important superposition pathway based on people's accessibility and relevant data. The findings revealed that although the size of green spaces is critical, their location is equally important. This finding aligns with Jang et al. (2020), who concluded that accessibility should be comprehensively examined by considering more variables than merely metric distance. The subsequent important finding is that before adding any more green spaces to the urban fabric, existing ones regarding their place within the city spatial configuration should have an accessibility analysis, and then, they should decide and plan for future parks and green spaces in line with Penang Green Agenda 2030. Finally, superposition of the existing data and space syntax maps can pave the way to understand existing green spaces and find suitable locations for future plans. This research method can particularly deliver implications and information for governmental decision-makers in the urban greenery policy sector on establishing better strategies and techniques concerning urban green spaces to prevent triggering sustainability problems.

4.1 Limitations and directions for future studies

Despite the significant contribution of the study to urban planning studies, limitations should be acknowledged for future work as well. Without a doubt, many factors, such as cognition maps, quality of the street appearance, or size of pavements and streets, are effective in the accessibility of urban green spaces. However, the present study mainly focused on the relationship between space syntax measures relevant to accessibility and the selected green spaces area. To better assess the accessibility of urban green spaces, future studies can consider the local peoples' travel method and a comprehensive analysis of neighbourhood

land-use patterns to understand the possible benefits from such spaces. A questionnaire survey might also enhance the clarity of residents' objective accessibility and actual usage of the existing green spaces. Therefore, the survey may help approve whether the obtained results in the study coincide with residents' actual perception of accessibility. Among other limitations, the adverse climate changes could be attributed to various factors, including local microclimatic and geomorphological conditions. As a result, these conditions need to be addressed in advance through sophisticated spatial planning and design of urban areas concerning the forecasted climate change. Additionally, collecting data from various cities from different climates is helpful to have more comprehensive results.

Appendix

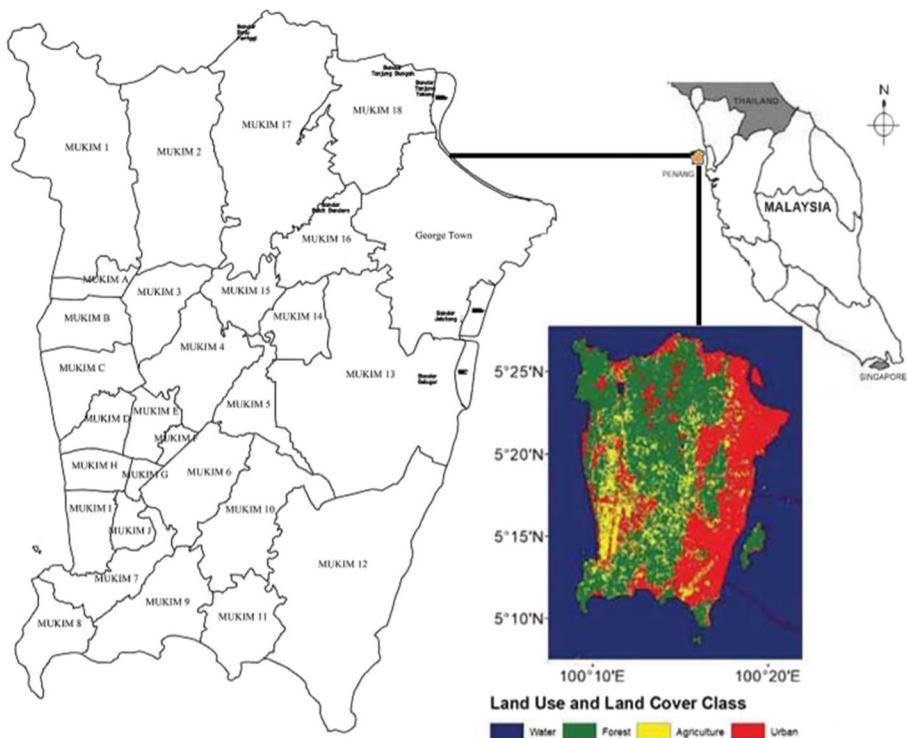### Appendix A: Map of the location of Penang Island

See Fig. 6.

Fig. 6 Location of Penang Island, contributing Mukim and percentage of land cover

Appendix B: Details of Penang urban green spaces regarding their regions (Mukim)

See Table 3.

Table 3 Penang urban green spaces and their regions (Mukim)

	Park	Region (Mukim)
1	Fountain Garden	George Town
2	Friendship Park	George Town
3	Penang Municipal Park	18
4	Armenian Park	George Town
5	Prangin (SiaBoey) Park	George Town
6	New Neighbourhood Park	George Town
7	Taman Lalu Lintas Park	George Town
8	Westland Sports Excellence Centre	George Town
9	Padang Polo	18
10	SDA field	18
11	Esplanade Park	George Town
12	Penang Botanic Gardens	18
13	Sorok Sungai penang2 park	George Town
14	Japanese Garden	13
15	Energy Bagua Taman Hikmat	13
16	Recreation Park Northern Region	13
17	Raffel Park	13
18	Penang bicycle park	13
19	Pekaka Park	13
20	Taman Sri Nibong Park	12
21	Persiaran Bayan Indah Recreation Park	12
22	Penang Golf Club	10
23	Island Glades Playground	13
24	Relau Metropolitan Public Gardens	5

Appendix C: Definition of space syntax measures based on the axial map

Street integration, a key space syntax measure, shows how "accessible" a street segment is topologically from all other street segments within a defined area (e.g., a certain distance from the centre of the street). Within the urban spatial network, the more accessible spaces (or spaces with a higher degree of integration) are inclined to gain higher levels of individuals' presence and activities, and less accessible spaces (or spaces with a lower degree of integration) are inclined to be mostly empty. Global integration indicates how easily one particular space can be reached from all other spaces in the whole network and is an indicator of syntactic accessibility (referred to as Rn). A space with a higher degree of global integration shows the proper accessibility of that space in the system, which needs to pass fewer spaces to reach that space (Hillier, 2007) and from the theoretical point of view, those spaces are easily and more frequently visited. Similarly, the local integration measure connects one space with its surrounding spaces (Li et al., 2019). It measures mean depth to three changes of direction away from a given space. R3 is widely accepted as the local scale due to the network area.

Choice value is also defined by (Hillier, 1984) as the degree to which a given street belongs to the shortest path between any pairs of streets in a network. Indeed, when a large number of shortest connection paths intersect a space, that space offers a high level of

choice. Similar to integration, the choice value can be calculated locally and globally. The robustness and importance of the choice value confirm that when moving to different destinations, individuals typically tend to choose the visually shortest path among the competitive paths in a network. The choice value has currently been covered in the space syntax literature. However, it has a reliable and robust correlation with individuals' presence.

Appendix D: Selected green spaces area and their syntactical measures

See Table 4.

Table 4 The selected green spaces and their space syntax measures

	Park	Area (ha.)	Integration (Rn)	Integration (R3)	Choice (Rn)	Choice (R3)
1	Fountain Garden	0.23	0.260	2.300	$3.235*10^5$	264.000
2	Friendship Park	0.42	0.249	1.817	$0.281*10^5$	58.000
3	Penang Municipal Park	9.94	0.247	1.108	$0.282*10^5$	64.500
4	Armenian Park	0.25	0.269	1.759	$2.596*10^5$	218.500
5	Prangin (SiaBoey) Park	1.49	0.274	2.111	$2.473*10^5$	321.200
6	New Neighbourhood Park	0.80	0.287	2.118	$0.988*10^5$	116.000
7	Taman Lalu Lintas Park	0.91	0.276	2.406	$3.151*10^5$	222.400
8	Westland Sports Excellence Centre	1.77	0.261	1.982	$0.321*10^5$	66.000
9	Padang Polo	7.00	0.283	1.954	$91.453*10^5$	96.000
10	SDA field	2.01	0.271	1.979	$39.364*10^5$	148.750
11	Esplanade Park	6.08	0.255	1.850	$2.068*10^5$	507.000
12	Penang Botanic Gardens	16.75	0.231	1.460	$5.732*10^5$	26.660
13	Sorok Sungai penang2 park	0.42	0.274	1.883	$0.706*10^5$	124.000
14	Japanese Garden	1.14	0.304	1.928	$89.993*10^5$	61.000
15	Energy Bagua Taman Hikmat	0.54	0.294	2.031	$1.115*10^5$	148.660
16	Recreation Park Northern Region	2.00	0.310	1.110	$0.603*10^5$	71.250
17	Raffel Park	1.51	0.261	2.248	$0.462*10^5$	121.500
18	Penang bicycle park	1.77	0.338	2.001	$302.08*10^5$	183.500
19	Pekaka Park	1.39	0.304	2.238	$3.45*10^5$	216.000
20	Taman Sri Nibong Park	2.99	0.289	2.001	$39.364*10^5$	129.160
21	Persiaran Bayan Indah Recreation Park	0.58	0.296	1.500	$0.544*10^5$	30.000
22	Penang Golf Club	41.00	0.279	1.348	$16.504*10^5$	33.500
23	Island Glades Playground	1.00	0.294	2.489	$4.954*10^5$	214.400
24	Relau Metropolitan Public Gardens	81.00	0.204	1.018	$28.26*10^5$	79.500

Appendix E: Overall view of public green spaces from the smallest to largest metric area and their space syntax measures

See Table 5.

Table 5 The 24 public green spaces from the smallest to largest metric area and their space syntax measures

Park	Type	Area (ha.)	Integration (Rn)	Integration (R3)	Choice (Rn)	Choice (R3)
Fountain Garden	Playing lot	0.23	0.26	2.3	$3.235*10^5$	264.000
Armenian Park	Playing lot	0.25	0.269	1.759	$2.596*10^5$	218.50
Friendship Park	Playing lot	0.42	0.249	1.817	$0.281*10^5$	58.000
Sorok Sungai penang2 park	Playing lot	0.42	0.274	1.883	$0.706*10^5$	124.000
Energy Bagua Taman Hikmat	Playing lot	0.54	0.294	2.031	$1.115*10^5$	148.660
Persiaran Bayan Indah Recreation Park	Playing lot	0.58	0.296	1.5	$0.544*10^5$	30.000
New Neighbourhood Park	Local play area	0.8	0.287	2.118	$0.988*10^5$	116.000
Taman Lalu Lintas Park	Local play area	0.91	0.276	2.406	$3.151*10^5$	222.400
Island Glades Playground	Local play area	1	0.294	2.489	$4.954*10^5$	214.400
Japanese Garden	Local play area	1.14	0.304	1.928	$89.993*10^5$	61.000
Pekaka Park	Local play area	1.39	0.304	2.238	$3.45*10^5$	216.000
Prangin (SiaBoey) Park	Local play area	1.49	0.274	2.111	$2.473*10^5$	321.200
Raffel Park	Local play area	1.51	0.261	2.248	$0.462*10^5$	121.500
Westland Sports Excellence Centre	Local play area	1.77	0.261	1.982	$0.321*10^5$	66.000
Penang bicycle park	Local play area	1.77	0.338	2.001	$302.008*10^5$	183.500
Recreation Park Northern Region	Neighbourhood	2	0.31	1.11	$0.603*10^5$	71.250
SDA field	Neighbourhood	2.01	0.271	1.979	$39.364*10^5$	148.750
Taman Sri Nibong Park	Neighbourhood	2.99	0.289	2.001	$0.641*10^5$	129.160
Esplanade Park	Neighbourhood	6.08	0.255	1.85	$2.068*10^5$	507.000
Padang Polo	Neighbourhood	7	0.283	1.954	$91.453*10^5$	96. 000
Penang Municipal Park	Local	9.94	0.247	1.108	$0.282*10^5$	64.500
Penang Botanic Gardens	Local	16.75	0.231	1.46	$5.732*10^5$	26.660
Penang Golf Club	Urban	41	0.279	1.348	$16.504*10^5$	33.500
Relau Metropolitan Public Gardens	Urban	81	0.204	1.018	$28.26*10^5$	79.50

Data availability All data generated or analysed during this study are included in this published article [and its supplementary information files].

Declarations

Conflict of interest The authors have no relevant financial or non-financial interests to disclose.

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