Towards a multiple-scenario approach for walkability assessment: An empirical application in Shenzhen, China

Abstract

In this paper, we propose to use a relational lens to understand walkability by acknowledging that what constitutes a walkable environment may vary considerably between pedestrians who have different needs, capacities, and purposes. A multiple-scenario approach is developed for assessing walkability, which recognises that in valuation, major components in walkability assessment may not always compensate each other. The analysis accommodates the idea that some components may be so important to certain people or in particular situations that they act as hard and non-negotiable constraints on valuation. Other components, however, are negotiable and lower scores can be compensated by, and traded against, higher scores on others. The procedures for applying the multiple-scenario approach to a rapidly developing city in China are presented, using environmental audit and reliability tests with data collected from four neighbourhoods of Shenzhen. The proposed approach offers an innovative way to account for different situations of assessing walkability, and challenges the traditional assumption of walkability by creating multiple scenarios that cater for the specific needs and preferences of pedestrians.

Keywords: neighbourhood walkability; multiple-scenario approach; street-level; built environment; heterogeneity; Shenzhen

1 Introduction

The accumulating evidence on the benefits of walking for physical and psychological health has attracted much interests from policymakers seeking to create a more sustainable urban environment (City of Melbourne, 2014; Transport for London, 2018). In line with this trend, many studies have been devoted to using different methods to assess walkability[1], including geographic information systems, environmental audits, and questionnaire surveys (Cerin et al., 2011; Cole et al., 2015; Koohsari et al., 2016; Pikora et al., 2003). However, most of these studies have seen walkability as a universal quality and assumed that a single walkability index can be applied in many different locations, contexts and situations (Frank et al., 2010; Lefebvre-Ropars et al., 2017; Nickelson, Wang, Mitchell, Hendricks, & Paschal, 2013; Zuniga-Teran et al., 2019). Such practice implicitly assumes that all pedestrians perceive and respond to the walking environment in a similar way. Nonetheless, this mode of thinking overlooks the fact that the ideas of what constitutes a walkable environment can vary considerably between different groups of people who have their own specific needs, purposes and preferences.

Moreover, individuals' experiences of walkability may be mediated by the places in which they have lived in the past or currently reside, as previous and recent experiences can shape how pedestrians interpret specific features of the built environment and their associations with the understanding of walkability (Chan et al., 2020). As a result, in this paper we argue that walkability needs to be understood in a more relational way, by considering how individuals with specific bodily capacities and understandings interact with various features of the built environment and other objects in places (Andrews, Hall, Evans, & Colls, 2012; Duff, 2010). Rather than seeing walkability as a single quality that unifies the environmental features, we argue that walkability should be reconceptualised as a relational quality that emerges from the current and past interactions between pedestrians and the environments in which they dwell, walk and use different means of transport.

[1] Acknowledging that walkability is a loosely defined but commonly used concept (Forsyth, 2015), in this study, we consider walkability as a multi-dimensional construct that measures how the built environment is constructed to support walking and active lifestyles. We limit our attention to studies that consider the role of built environment features in people's walking behaviour and experience only. Further discussion about typologies of other walkability assessment studies is available in Vale, Saraiva, & Pereira (2016).

To operationalise this concept, we apply the principle of non-compensatory decision rules to develop a set of walkability scenarios to assess walkability for different pedestrian groups or situations. This approach takes into account that for some pedestrians or in certain situations, certain environmental qualities must be present for a segment of a street or footpath to be considered walkable; its absence, or a low level of quality, cannot be compensated by the presence of other qualities. The five scenarios presented in this study can be regarded as a starting point to widen our understanding of walkability with a more flexible and relational perspective.

The literature on walkability assessment has been dominated by studies in the global North. Recently, studies from cities in less developed countries are growing but are still relatively scarce (Albers, Wright, & Olwoch, 2010; Habibian & Hosseinzadeh, 2018; Su et al., 2014; Sun, Webster, & Chiaradia, 2017). Given that the population density, urban structure and walking environment are hugely different between cities in the developed and developing countries (Alfonzo, Guo, Lin, & Day, 2014), studies that are focused specifically on understanding walkability in the developing world are essential. Although Shenzhen has been recognised as one of the most walkable cities in China (NRDC, 2014), it is also experiencing rapid urban expansion and growth in automobile ownership. The daily average number of walking trips made by Shenzhen citizen has been decreasing as indicated in the most recent travel characteristics survey (Shenzhen Urban Planning and Research Centre, 2017). In view of this situation, there is an urgent need to improve the understanding and assessment of walkability in this rapidly changing urban environment.

The aim of this paper is to present a multiple-scenario approach for walkability assessment and empirically apply this approach in selected neighbourhoods of Shenzhen. The approach allows us to reconceptualise walkability as a relational construct where the saliency of specific attributes may differ between population groups and/or according to the situation.

2 Literature Review

2.1 Walkability and relational thinking

The constant debates on the meaning of walkability in research, practice and public discussions did not prevent the frequency of its application, and large number of studies to date have developed tools and/or indices to measure walkability. In a recent literature review, Vale et al. (2016) categorised 80 studies that measures active accessibility into four major types based on their methodological and computational similarities, namely: distance-based, gravity-based, topographical or infrastructure-based, and walkability and walk score-type measures. Within this vast literature of walkability assessment, here, we focus specifically on two complementary strands of studies that emphasise the quantification of the built environment features that are important to people's walking behaviour and experience. The first strand of studies can be found more commonly in transportation and urban planning studies. They tend to use GIS tools to analyse built environment characteristics and develop quantitative indices to assess walkability (Cole et al., 2015; Frank et al., 2010; Glazier et al., 2012; Leslie et al., 2005; Neckerman et al., 2009; Tsiompras & Photis, 2017). These studies have provided a novel and direct way to quantify the walkability of the built environment. Nonetheless, walkability in these studies was assessed at a larger geographical scale, such as census tracts (Frank et al., 2010; Owen et al., 2007) and other administrative spatial units (Cho & Rodríguez, 2015). As a result, the components used to construct these indices focus more on capturing the density and diversity of land uses, such as residential or population density, land use mix, intersection density, retail floor area ratio, distance to nearest subway stops/parks/retail areas, while less attention has been placed on quantifying the smaller scale streetscape features along the footpaths[2] (Cho, & Rodríguez, 2015; Cole et al., 2015; Glazier et al., 2012).

Giving that walking is a much slower activity and pedestrians have more direct interaction with the surrounding environment during their walking trips (Clifton, Smith, & Rodriguez, 2007), the other strand of studies has focused more on the micro-scale of street-level attributes and design features such as footpath width, pavement flatness, presence of trees and various amenities, etc. in representing walkability. These studies have developed numerous environmental audit tools in developed countries (Clifton et al., 2007; Day, Boarnet, Alfonzo, & Forsyth, 2006; Millstein et al., 2013; Pikora et al., 2003) and developing countries (Albers, Wright, & Olwoch, 2010; Aghaabbasi, 2018; Su et al.,

[2] In this study, the term "footpath" is used to represent all types of walkways used by pedestrians, including walkways along the sides of a road and pedestrian only paths. The term "footpath" is used interchangeably with similar terms, like "sidewalk" and "pavement".

2014; Taleai & Amiri, 2017); for walking routes with specific purposes (Sun, Webster, & Chiaradia, 2017; Troped et al., 2006); and in different settings, like rural areas (Fisher, Richardson, & Hosler, 2010; Scanlin, Haardoerfer, Kegler, & Glanz, 2014) and the workplace (Dannenberg, Cramer, & Gibson, 2005). In general, these audit tools have paid more attention to the objectively measurable physical features. Subjective features, such as comfort, attractiveness, smells and sound, which have been identified to have significant influence on walking experience in other studies have largely been overlooked (Cook, Bose, & Main, 2014; Ferrer, Ruiz, & Mars, 2015). The major environmental audit tools reviewed are shown in Table 1 below.

[insert Table 1]

Despite the substantial number of studies conducted on walkability and considerable efforts to assess walkability, the "relational turn" in human geography and the social sciences offers a new perspective to explore the fluidity of places and spaces as well as our understanding of walkability (Ettema & Schwanen, 2012; Hui & Walker, 2018; Jones, 2009). Scholars have sought to bring attention to the relational capacities of human bodies, and their encounters and interactions with multiple environmental features, other bodies and objects in places (Andrews, Hall, Evans, & Colls, 2012; Duff, 2010; Schwanen, Banister, & Bowling, 2012). Following their lead, we propose to reconceptualize walkability in a more relational way in which due consideration is given to the specific needs, capacities and preferences of pedestrians as well as their current and past interactions with the environments in which they dwell, walk and travel (Chan et al., 2021). Taking the variability of pedestrians' needs, capacities and preferences into consideration, the concept of walkability can move from a previous "absolute" view towards different "relational" conditions (Ingold & Vergunst, 2008; Jones, 2009; Stevenson & Farrell, 2018).

Recognising that walkability can be reconceptualised in a more relational way by considering the differentiated needs, capacities and preferences of pedestrians and their interactions with the environment, we also need to consider how such ideas can be incorporated into practical walkability assessment. This leads us to rethink the assumptions about the extent to which different qualities can compensate for each other in existing walkability assessment studies.

2.2 Decision rules in walkability assessment

In measuring and calculating the walkability index, many studies have assumed a fully compensatory structure among the major qualities and attributes concerned in walkability assessment, implying that a low score on one dimension can be compensated by a high score on another. For instance, in the widely applied walkability index (Frank et al., 2010; Leslie et al., 2005), the additive rule is applied to sum the z-scores of all walkability qualities together. In other studies, researchers assign certain weightings to each walkability quality based on results from questionnaire surveys or factor analysis and summarise the scores of each quality (Blečić et al., 2015; Glazier et al., 2012; Tsiompras & Photis, 2017). However, the use of weightings only considers the relative importance of different walkability qualities, which does not fully account for the fact that certain factors have decisive and non-negotiable influence on walking behaviour, especially for specific population groups (e.g. older adults, women and people with disabilities) (Ferrer et al., 2015; Golan, Wilkinson, Henderson, & Weverka, 2019; Gullón et al., 2015). These factors could be regarded as hard conditions that have to be met for some pedestrians to be able and/or willing to walk on that street segment or in that environment. In this case, assuming a fully compensatory structure among the walkability qualities might oversimplify the complex situation and unable to reflect the true walkability for certain pedestrians.

As individuals make their daily decisions based on various decision rules and heuristics, we draw on insights from the behavioural sciences in order to better consider the relationships between various qualities of walkability in constructing a walkability index. Behavioural scientists have identified numerous decision strategies to further our understanding of the complexity of people's evaluation and decision-making processes. These decision rules include lexicographic rules (Tversky, 1969), elimination-by-aspects (EBA) (Tversky, 1972), and conjunctive / disjunctive rules (Einhorn, 1970). A key distinguishing factor among these decision rules is the extent to which trade-offs can be made between the attributes within the model. A rule is considered compensatory if the decision maker can trade a low value on one dimension against a high value on another dimension; it is non-compensatory if deficiencies in one dimension cannot be compensated by surpluses in another dimension (Payne, 1976).

In view of these concerns, it is necessary to reconsider the reliance on compensatory mechanisms in existing walkability assessment studies and to include non-compensatory mechanisms to consider the irreplaceable nature of certain qualities in walkability assessment. In this case, we propose to use a combination of multiplicative and additive functions to create multiple scenarios of walkability indices for walkability assessment.

3 Methods

3.1 Research procedures

This section introduces the procedures for conducting the multiple-scenario and relational walkability assessment, which consists of four major parts, namely: tool development, data collection, data preparation, and scenario construction. Figure 1 shows the major steps involved in this approach.

[insert Figure 1]

The first stage was to identify the major qualities of walkability and select appropriate measurement items to be included in the environmental audit tool. This was done with the help of a combination of methods, including literature review, semi-structured interviews, and the researcher's own experience of the local environment. After the tool was developed, an environmental audit was conducted in randomly selected samples of footpaths within the selected neighbourhoods, to collect data on walkability. The next stage was data preparation. Inter-rater and intra-rater reliability tests were performed to ensure the quality of the measurement items included for further analysis. Through a series of aggregation and scoring procedures, the data was transformed into scores to represent specific qualities of walkability. The final stage was the walkability scenario construction, where various combinations of compensatory and non-compensatory decision rules were applied to create different walkability scenarios for assessment.

3.2 The case of Shenzhen

As one of China's largest metropolitan cities, Shenzhen is experiencing rapid urban transformation and sprawl. Urban development has created neighbourhoods with diverse and distinctive characteristics, for instance, with varied road and pedestrian network structures, different block sizes and land use mix. This distinctive neighbourhood environment may influence people's walking behavior. For instance, a recent report noted that residents living in the outer urban neighbourhoods in Shenzhen conduct more walking trips than those living in inner urban neighbourhoods (Shenzhen Urban Planning and Research Centre, 2017). In order to capture the variability of Shenzhen's neighbourhood environments and its associations with walkability, we purposefully selected four neighbourhoods for analysis, including Xinzhou (Inner urban - High accessibility, IH), Xinsha (Inner urban - Low accessibility, IL), Shangjing (Outer urban - High accessibility, OH) and Huilongpu (Outer urban - Low accessibility, OL), as shown in Figure 2.

[Insert Figure 2]

3.3 Development of environmental audit tool

This process has involved two steps: 1) identifying major walkability qualities and 2) selecting measurement items. Major walkability qualities were selected on the basis of a synthesis of existing literature. In total, six qualities were identified: Land use and destinations (LAND), Safety (SAFE), Aesthetics (AEST), Amenities (AMEN), Footpath design and condition (PATH), and Subjective assessment and experience (SUBJ). Next, three methods were used in combination to select the measurement items: First, a comprehensive review of the walkability assessment literature was performed to identify the measurement items used in previous studies. Second, semi-structured interviews were conducted with local residents in Shenzhen to understand their views on the built environment features that contribute to walkability. Third, the lead author conducted a three-month fieldwork in the selected neighbourhoods to familiarise himself with the local context and immerse himself into the local walking environment (Phillips & Johns, 2012). This fieldwork not only offered a valuable opportunity for the lead author to observe, sense and experience the walking environment in the study areas, but also provided important place-sensitive insights about which measurement items should be selected and how they should be specified.

The combination of semi-structured interviews and fieldwork resulted in the identification and inclusion of various previously not considered items such as the volume of sound, air quality, and presence of a police stand. In the end, the resulting environmental audit tool is comprised of 87 measurement items, as shown in Table 2 (A brief review of the measurement items used in existing studies is included in Appendix 1).

[insert Table 2]

3.4 Conducting the environmental audit

An environmental audit was conducted with the approach developed in the previous section and a stratified random sample of footpaths in each selected neighbourhood was examined. Four professional surveyors were recruited to conduct the environmental audit. All of the surveyors had to participate in both in-class and on-site training by the lead author before performing the audit. First, a two-hour in-class training addressed the aim of the audit, its procedures, and the standard of the assessment. Detailed descriptions and photos of the environmental features to be assessed were provided to allow the surveyors to identify and familiarise themselves with the environmental features of the local environment. After that, an on-site training was provided during which the surveyors conducted a pilot assessment. Their performances were monitored before the actual audit was conducted. The environmental audit tool is included in Appendix 2.

Footpaths in this study were defined as roads, streets or pedestrian paths bounded by two consecutive junctions or cross streets. Footpaths were categorised into three types: major footpaths (footpaths alongside major roads), minor footpaths (footpaths alongside non-major roads), and other passageways (other informal footpaths and small alleys). This study pays particular attention to assessing the walkability of informal paths and alleys that have typically been excluded from consideration in most existing studies, because the lead author’s fieldwork has demonstrated that these paths were often used by pedestrians. Major and minor footpaths were categorised using the road hierarchy published by Shenzhen Planning and Natural Resources Bureau, while other passageways were identified during the lead author’s fieldwork. If the footpaths were longer than 200m, they were subdivided into separate segments to ensure consistency in segment length and allow for better comparison across footpaths. Although previous studies had shown that auditing 25% of randomly selected footpaths within a neighbourhood could provide sufficiently reliable estimation of walkability (McMillan, Cubbin, Parmenter, Medina, & Lee, 2010), we randomly selected 50% of major footpaths and 30% of minor footpaths and 30% of other passageways in each neighbourhood for our audit to err on the side of caution. In total, 406 footpath segments were assessed, including 132 segments of repeated measures for the reliability tests.

3.5 Data preparation

Scoring of data collected from environmental audit

The data collected from environmental audit consists of three types of data: dichotomous items, ordinal items, and continuous items. Dichotomous items (no/yes) were scored as 0/1 to indicate the presence of certain attributes, e.g. presence of streetscape features, like fountains and sculptures. Ordinal items with multiple categories were scored as 0, 1, 2 (or more) to capture frequency or magnitude of environmental features. For example, the item measuring tree coverage was scored from 0 to represent no tree coverage and 4 to represent 76-100% of tree coverage along the segment. Continuous items were categorised into separate groups based on relevant standards. For example, $PM_{2.5}$ was categorised into 3 groups: <36μg/m^3, 36-75μg/m^3 and >75μg/m^3, based on national standards[3]. For ease of interpretation, all items were scored so that higher value indicates better walkability.

Reliability tests

To ensure the reliability of the measurement items, both intra-rater and inter-rater tests were conducted (as shown in Table 3 and 4). Intra-rater reliability was assessed by comparing a surveyor's repeated assessments of the same segment, and inter-rater reliability was evaluated by comparing the results of paired surveyors for the same segment. Cohen's kappa (k) and the intraclass correlation coefficient (ICC) were calculated for ordinal and frequency variables respectively. We also computed the percentage agreements to consider the reliability of those items that exhibit little variation (Day et al., 2006). For items with fewer than 3 observations, kappa and ICCs were not computed, but instead percentage agreement was presented with the caution

[3] Ambient air quality standards (GB3095-2012) published by Ministry of Ecology and Environment of the People's Republic of China

that agreement due to chance may be high.

[insert Tables 3 and 4]

We found that measurement items in "Subjective assessment and experience" presented lower reliability compared to other walkability qualities for both intra-rater and inter-rater reliability tests, and this result is consistent with previous studies (Sun et al., 2017; Pikora et al., 2003). Nonetheless, moderate to high levels of percentage agreement were observed from these items. Considering the results from the reliability tests, we removed 16 items with low kappa/ICCs or without sufficient variability and retained 71 items for final analysis[4].

Data aggregation

After the reliability tests, the next process was to further aggregate the data for analysis. Because there are multiple measurement items in the audit tool, we followed a similar approach as in Millstein et al.'s (2013) study to organise the measurement items into a tiered classification system, ranging from measurement item (1st tier – lowest level) to construct (2nd tier), walkability sub-quality (3rd tier) and walkability quality (4th tier – highest level) (as illustrated in Table 2). To illustrate the data aggregation process, we use one of the walkability qualities – "Land use and Destinations (LAND)" as an example. In the first tier, we summed the scores for the measurement items that belong to a single construct into a single numerical value. For instance, to capture the presence of food-related destinations, three measurement items (Supermarket / Fresh food market, Restaurant, 24hr convenient store) were added up to form a single construct to represent food-related destinations. The same procedure applies to the other four constructs within this walkability sub-quality (commercial/retail, leisure related, office/institutional, and transport related destinations). As the constructs have different ranges and distributions, they were normalised using the following formula to bring the values into the (0, 1) range:

[4] Some of the measurement items were grouped into a single question in the audit form as shown in Appendix 2 for convenience in implementation. Please refer to Table 2 for the number of measurement items retained after reliability tests.

$$X' = \left(\frac{X - X_{min}}{X_{max} - X_{min}}\right)$$

X is the selected variable; X' is the normalised value of the variable; X_{max} and X_{min} are the maximum and minimum values respectively. After that, we further use average scores of the five constructs within the sub-quality ("Destinations") to combine into walkability sub-quality scores. Finally, the sub-quality scores were first averaged (in this case, two sub-quality scores of "Residential land use" and "Destinations") and then rescaled into values between 0 to 10, to form the walkability quality scores ("Land use and destinations"). This method of data aggregation is chosen because it is not only simple in operation, but it also allows the examination of the walkability attributes at various tiered levels of specificity.

3.6 Construction of walkability scenarios

After the data aggregation process, the walkability quality scores for all footpaths were computed, this section then presents the application of different decision rules to derive the five walkability scenarios and their potential applicability to different pedestrian groups. The first two scenarios present the two extremes of the spectrum (completely compensatory and non-compensatory), the other three scenarios are partial non-compensatory (with certain walkability qualities considered non-compensatory), and these scenarios try to measure walkability for specific population groups and/or in specific situations more realistically. However, the walkability scenarios presented here are by no means comprehensive. Different scenarios based on other method of combination could be developed in the future.

Scenario 1 – Completely compensatory

This scenario presents the most traditional and widely adopted method in calculating walkability index in existing studies, by assuming that all walkability qualities can be compensated by one another. The walkability index is computed by adding the scores of six walkability qualities together. This method is common as it is easiest to compute and able to provide a general picture of the data. The walkability index can be calculated by using the following formula:

$$WS_1 = LAND + SAFE + AEST + AMEN + SUBJ + PATH$$

Scenario 2 – Completely non-compensatory

In this scenario, we assume that none of the six walkability qualities can be compensated by the others. Thus, the scores of six walkability qualities were multiplied to get the walkability index. For example, a footpath with a lower score in aesthetics cannot be compensated by a higher score in another quality, e.g. safety. Hence, a lower score in any one of the qualities will significantly lower the overall walkability using this completely non-compensatory method of calculation. The walkability index can be calculated by using the following formula:

$$WS_2 = LAND \times SAFE \times AEST \times AMEN \times SUBJ \times PATH$$

Scenario 3 – Preference for short distances and safety

This scenario represents the circumstances in which the scores on the two qualities of land use and destinations, and safety are considered to be hard and non-compensatory criteria in assessment of walkability. This scenario assumes that pedestrians need or have a strong imperative to walk for short distances (e.g. because of poor physical condition or time constraints) and consider a safe walking environment as necessary. In this instance, having destinations in close proximity and being able to access them via safe routes are both essential. This scenario can be applied especially to pedestrians who have limited ability to walk for long distances and pedestrians who regard safety as critical factor for their walking experience, including older pedestrians and children. Other qualities are considered compensable by each other in this scenario. The walkability index can be calculated by using the following formula:

$$WS_3 = LAND \times SAFE \times (AEST + AMEN + SUBJ + PATH)$$

Scenario 4 – Emphasis on footpath quality

This scenario highlights the non-compensatory nature of the qualities of footpath design and condition, and amenities in computing the walkability index. This scenario assumes that the features and conditions of footpath are essential criteria for making walking attractive to certain people. The scenario is usable to assess walkability for pedestrians that have particular concerns over various aspects of footpath quality. For example, smooth surface of footpath is essential for pram users; having sufficient width of footpath and presence of various amenities are essential for people with disabilities or mobility impairments. The other four qualities can be compensated by each other in this scenario. The walkability index can be calculated by using the following formula:

$$WS_4 = AMEN \times PATH \times (LAND + AEST + SAFE + SUBJ)$$

Scenario 5 – Emphasis on sensory experience

This scenario assumes that aesthetics and subjective experience as non-compensatory, indicating the circumstances in which sensory experience (e.g. pleasure and comfort) such as those depending on various stimuli from the environment (e.g. lights, sounds, smells) are critical constituents of walkability (Mehta, 2008). This scenario is particular useful for specific purposes of walking trips in which pedestrians pay extra attention to sensory experiences of walking, such as for leisure or recreational trips. The other four qualities are regarded as compensatory in this scenario. The walkability index can be calculated by using the following formula:

$$WS_5 = AEST \times SUBJ \times (LAND + AMEN + SAFE + PATH)$$

4 Results

This results section consists of two parts. The first sub-section presents the descriptive statistics and one-way ANOVA to compare the overall walkability among neighbourhoods for the five walkability scenarios; the next sub-section further compares the changes in walkability for footpaths when assessed using different scenarios and highlights the applicability of each walkability scenario in different situations and conditions.

4.1 Descriptive statistics

Since the walkability scores in the five scenarios have different value ranges, the walkability scores for each footpath were further transformed into z-scores for comparison purpose. The descriptive statistics of the walkability scenarios are presented in Table 5 below. First, the use of the traditional compensatory approach (WS_1) for walkability assessment results in a higher mean walkability compared to other scenarios. In contrast, Scenario 2 (WS_2) results in the lowest mean walkability. Next, a comparison of footpath types indicates that major footpaths are the most walkable (highest mean walkability), followed by minor footpaths and other passageways across all five scenarios. But the differences between the footpath types vary across the scenarios. For instance, the mean walkability for major footpaths is about six times higher than for other passageways in WS_2, which is much higher than in the other scenarios (ranging from 1.78 to 3.39).

The mean walkability of the four neighbourhoods were compared using one-way ANOVA (Table 6). No statistically significant differences can be found for WS_1 ($F=2.459$, $p=.063$) and WS_3 ($F=1.286$, $p=.280$), but statistically significant differences at $p<0.05$ can be observed in the other scenarios (WS_2, WS_4 and WS_5) using fully or partially non-compensatory methods. The outer urban - low accessibility neighbourhood is, on average, the most walkable and the inner urban - high accessibility neighbourhood is the least walkable in all scenarios except for WS_3. In WS_3, the outer urban - high accessibility neighbourhood ranked second, followed by the inner urban - low accessibility neighbourhood. This is due to the higher scores for the walkability quality "land use and destinations" in the outer urban - high accessibility neighbourhood. This observation is interesting because unlike the conventional understanding that high local accessibility neighbourhoods are usually more walkable, this result demonstrated that the accessibility level of a neighbourhood might not necessary associated with how walkable a neighbourhood is using the multiple-scenario approach for walkability assessment. Likewise, the post-hoc tests also demonstrated that the differences in walkability among neighbourhoods vary in each scenario, showing that these walkability scenarios capture different aspects of walkability.

[insert Tables 5 and 6]

4.2 Comparing relative walkability of footpaths

This section further compares the changes in walkability for footpaths in each scenario with reference to Scenario 1 (WS_1). We first ranked all of the footpaths into ten equal groups based on their walkability scores ranging from 1 (least walkable) to 10 (most walkable) for each scenario. The walkability of footpaths in decile groups for Scenarios 2 to 5 (WS_2 to WS_5) were then compared with the reference scenario (WS_1) respectively by using a number of tables (similar to that presented in Figure 3). If the walkability indices of footpaths are similar between the reference scenario (WS_1) and other scenarios (WS_2 to WS_5), most of the footpaths will be concentrated along the diagonal line. Otherwise, more scattered patterns will be observed. In this way, we can examine the changes in relative walkability of footpaths in different scenarios.

[insert Figure 3]

The results of the changes in walkability (in decile groups) of WS_2 to WS_5 (compared with WS_1) are summarised in Table 7 below. The changes between scenarios were classified into five groups: Major decrease (decrease by more than one decile group); Minor decrease (decrease by one decile group); No change; Minor increase (increase by one decile group); Major increase (increase by more than one decile group). As shown in Table 7, the relative walkability of footpaths changed substantially compared to the reference scenario (WS_1). For example, a large proportion of footpaths have increased in relative walkability (19.3% minor increase and 28.1% major increase) in WS_3, indicating that many footpaths that are less walkable in WS_1 became more walkable in WS_3. To further disaggregate the changes in relative walkability by neighbourhoods and types of footpath, we present two separate figures (Figure 4 and 5).

[insert Table 7]
[insert Figures 4 and 5]

The discussion below concentrates on showing how the relative walkability of footpaths varies in different scenarios and how these scenarios can be applied in different situations to understand walkability in a more relational way. In Scenario 3 (WS_3) (top right corner of Figure 4), about 40% of footpaths in the two low accessibility neighbourhoods (Xinsha and Huilongpu) become less walkable, while more than 50% of footpaths in the high accessibility neighbourhoods (Xinzhou and Shangjing) become more walkable. Such observation might be attributable to the more diversified land uses in neighbourhoods with higher accessibility. For example, retail and commercial activities are more commonly found on footpaths within these two high accessibility neighbourhoods, so pedestrians are more likely to perceive these footpaths as safer. When the dimension of "safety" and "land use and destinations" are non-compensatory qualities in WS_3, higher walkability scores are observed in these high accessibility neighbourhoods. This scenario could be applied to pedestrians who are especially concerned about the ability to reach destinations within short distances and regard safety as a critical factor that influences their walking intention and experience, such as children and older adults (Ferrer, Ruiz, & Mars, 2015). If information on walkability were provided to these pedestrians, they might want to make use of this scenario to identify footpaths and routes offer safe and short-distance walking trips without disregarding other dimensions of walkability.

In Scenario 4 (WS_4) (bottom left corner of Figure 4), a larger proportion of footpaths in the high accessibility neighbourhoods (IH and OH neighbourhood) have decreased in walkability (27% (OH) and 36% (IH)). This reflects that many footpaths in these neighbourhoods are of relatively poor quality and that "footpath design and condition" and "amenities" are non-compensatory qualities in WS_4. This situation is especially significant in Xinzhou (IH) because of the presence of urban villages within this neighbourhood. Many footpaths within the urban villages are characterised by poor design and lack of maintenance because of their rapid and unregulated developments in the past. This scenario (WS_4) can help to identify neighbourhoods and footpaths that require improvements in terms of footpath quality, such improvements can significantly improve the pedestrian environment in these areas. More importantly, this scenario is especially suitable for assessing walkability for pedestrians that have special concern over the quality of footpath, such as pram users, people with disabilities or mobility impairments (Imrie, 2000). In practice, this scenario (WS_4) can also be applied to examine the pedestrian network in proximity to specific destinations, such as hospitals and healthcare centres. The walking environment around these destinations requires special attention to ensure pedestrians (e.g. patients) can walk without being affected by obstructions on footpath.

For Scenario 5 (WS_5) (bottom right of Figure 4), distinctive pattern can be observed in Xinsha (IL). Here only 13% of footpaths decrease in walkability compared to the reference scenario, which is much lower than for the other three neighbourhoods (around 30%). At the same time, more than 30% of footpaths in this neighbourhood become more walkable. This observation reveals that footpaths in Xinsha performed better in terms of aesthetics and sensory experience, although Xinsha was located in the outer urban area of Shenzhen and have low local accessibility, many of its footpaths are designed in a way that are more conducive for walking (with more aesthetic features and amenities). Given that aesthetics and subjective experience were positively associated with walking for leisure (Sugiyama et al., 2012), WS_5 can be especially relevant for pedestrians who pay special attention to sensory experiences of walking. For example, the results for this scenario could be used to provide information for leisure or recreational pedestrians to identify enjoyable and aesthetically pleasing footpaths, in this way, it is possible to increase pedestrians' satisfaction level of these trips.

When attention is directed towards relative walkability according to footpath type, the most noticeable observation is the increase in relative walkability for other passageways in Scenario 3 (WS_3) (top right corner of Figure 5). In this scenario, more than 44% of the other passageways increased in walkability compared to the reference scenario. This shows that unlike traditional understandings that regard these other passageways as unimportant in walkability assessment, these other passageways are really quite safe and many destinations can be found along these paths.

5 Discussion and Conclusion

In this study, we propose a new lens to see walkability as relational and emerging from the interactions between the pedestrians and their environment. Since a footpath that is regarded as walkable to one individual may not perceived to be equally walkable by others, it is important to consider the heterogeneity of pedestrians and their diverse needs, capacities and preferences in walkability assessment. The proposed multiple-scenario approach for walkability assessment advanced our current understanding and evaluation of walkability in the following ways.

Conceptually, we question the traditional assumption applied in existing studies that various aspects of walkability can compensate each other and applied the additive rule in calculating the walkability index. Although some existing studies have started to apply different weightings to account for the varying perspectives of walkability for various pedestrian groups (Golan et al., 2019; Moura et al., 2017), nonetheless, it is still largely assumed that all aspects of walkability identified by the researchers are important to pedestrians but with different levels of intensity for different pedestrian groups. But in reality, the assessment of walkability for a given type of footpath or street segment by a single pedestrian can differ significantly from one situation to the next and also differ from that by another individual with a similar sociodemographic background in a broadly comparable situation. Hence, the application of non-compensatory decision rules in walkability assessment as proposed in this study moves beyond the conventional assumptions implied. In this study, we proposed that in valuation of walkability, the major qualities in walkability assessment may not always compensate each other; rather, certain aspects in walkability are so important to certain people or in certain situations that they act as hard constraints on valuation and therefore cannot be compensated by other aspects. At the same time, certain aspects may be negotiable and it is possible that lower scores are compensated by, and traded against, higher scores on other factors. In practice, it is possible to develop walkability scenarios based on walkability qualities and elements that are regarded as important to pedestrians, and disregard other walkability qualities and elements that are unimportant. This more relational view of walkability assessment can complement the more "absolute" view adopted in exiting walkability assessment studies.

This practice can be regarded as a starting point for future studies to consider using other decision rules for walkability assessment. Some of these decision rules, like lexicographic rules (Tversky, 1969) or elimination-by-aspects (EBA) (Tversky, 1972) may provide new insights for researchers to consider pedestrians' views in deciding what constitutes a walkable environment and how researchers can develop new methods for assessment. The five walkability scenarios proposed and tested in this study are by no means exhaustive, but serving more as an early attempt to show scholars, policymakers and practitioners that it is possible to develop other possible walkability scenarios that match with their specific needs and requirements of local context for future walkability assessment.

Practically, the application of the proposed multi-scenario walkability approach is particularly useful in developing city contexts where data on the built environment and pedestrians' preferences on walkability are scarce. Even without detailed information about local residents' preferences on walkability, this approach can still be used to develop various scenarios to assess walkability for different (or specific) purposes. More importantly, following the ongoing trend of "smart city" development, walkability indices of the kind proposed here can be made accessible to all residents, possibly in the form of mobile phone applications (Neirotti et al., 2014). For example, most of the existing trip-planning applications only consider travel time as the sole criterion in route choice decision-making; the walkability of footpaths is rarely taken into consideration. If walkability indices are incorporated into these mobile applications, residents can make informed decisions on route choice and selection of residential location based on their own needs and preferences. Following this idea, it is even possible for future mobile applications to enable residents to decide which sets of environmental features and/or walkability qualities are non-compensatory for their walking trips. By doing so, walkability assessment can move from a top-down approach in which the local authorities or private companies provide information of walkability to the residents, to a bottom-up approach that allows residents to choose their own criteria and calculate their personalised walkability indices based on their specific needs and preferences. This approach can help to facilitate people's walkability as well as their well-being in the long term by recognizing individual's differentiated needs during different periods of their life-courses (Li & Chan, 2020).

The limitations of this study should be acknowledged. First, this study empirically tested the proposed multiple-scenario walkability approach with the case of a single city – Shenzhen, and focused in four selected neighbourhoods with different characteristics. In fact, it will be desirable for future studies to extend the scope of this study to more diversified neighbourhoods in Shenzhen and other cities in China. Collecting walking behaviour data in both Shenzhen and other cities in future studies can help to further verify the applicability of this approach and validate the walkability scenarios proposed in this study (Moura et al., 2017). Next, in this study, we have included 6 walkability qualities and 71 measurement items in the proposed environmental audit tool for walkability assessment, however, this list of measurement items is by no means exhaustive and universally applicable to other cities and contexts, therefore, future research can be conducted to identify other important walkability qualities and measurement items in assessing walkability and develop other meaningful walkability scenarios that can be applied to other population groups and/or in different situations (Wang & Yang, 2019).

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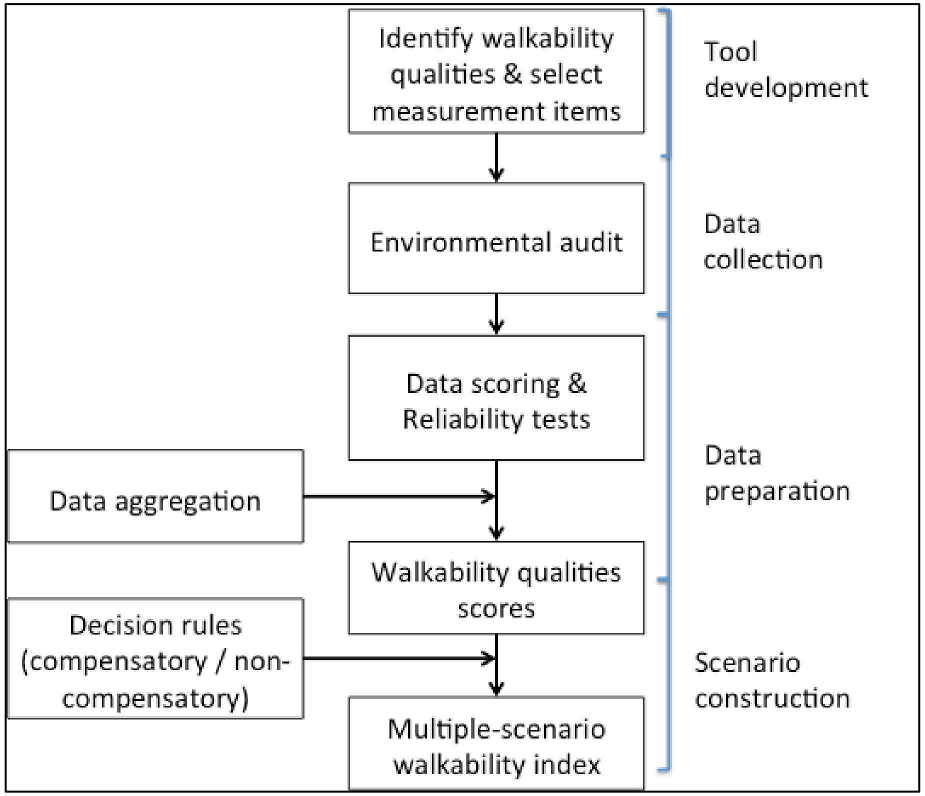

Figure 1 Procedures in conducting multiple-scenario walkability analysis

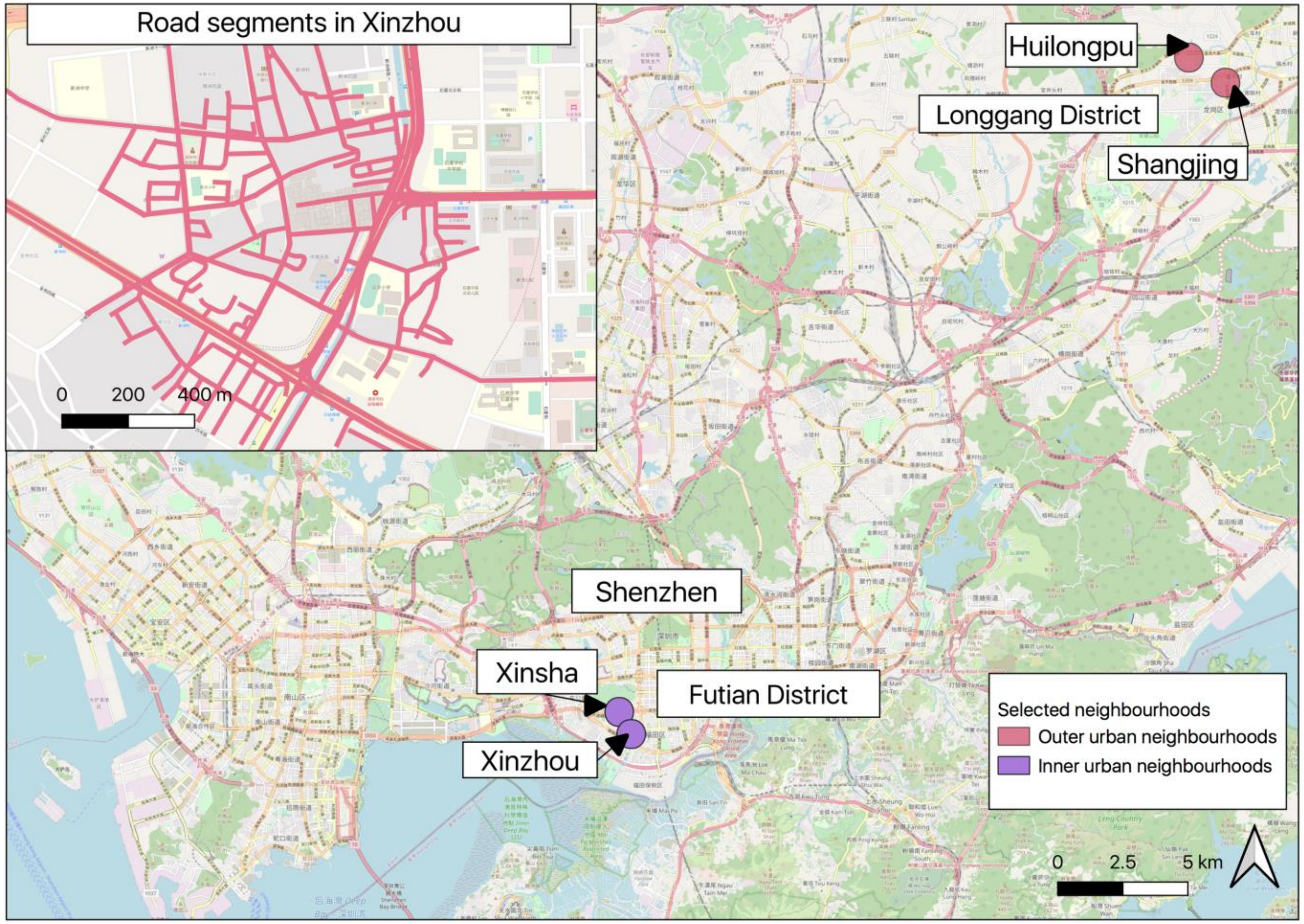

Figure 2 Location of selected neighbourhoods in Shenzhen

		Decile group of WS5										No. of observations
		1	2	3	4	5	6	7	8	9	10	
Decile group of WS1	1	20	6	1	0	0	0	0	0	0	0	27
	2	6	14	6	1	0	0	0	0	0	0	27
	3	1	4	12	8	3	0	0	0	0	0	28
	4	0	4	5	8	7	3	0	0	0	0	27
	5	0	0	1	7	8	8	4	0	0	0	28
	6	0	0	1	1	7	8	7	1	2	0	27
	7	0	0	1	1	3	6	9	7	1	0	28
	8	0	0	0	1	0	2	7	12	5	0	27
	9	0	0	0	0	0	0	1	7	14	6	28
	10	0	0	0	0	0	0	0	0	6	21	27
Total		27	28	27	27	28	27	28	27	28	27	274

Indicates two footpaths change from 6 (medium walkable) in WS_1 to 9 (highly walkable) in WS_5

Figure 3 Example of changes in decile group of WS_5 compare to reference scenario (WS_1)

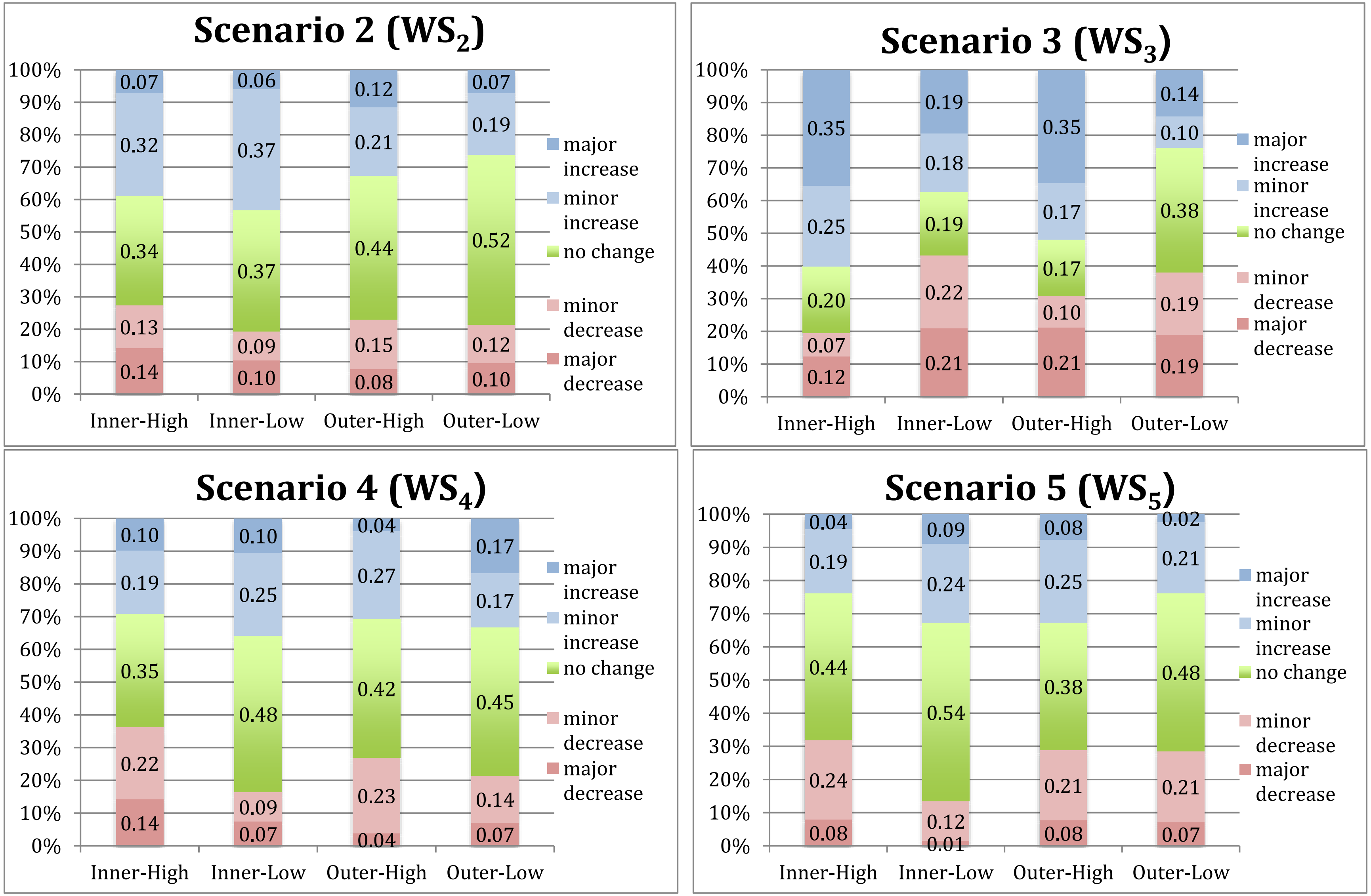

Figure 4 Summary of the changes in walkability scenarios (WS_2 to WS_5) compare to the reference scenario (WS_1) by neighbourhoods

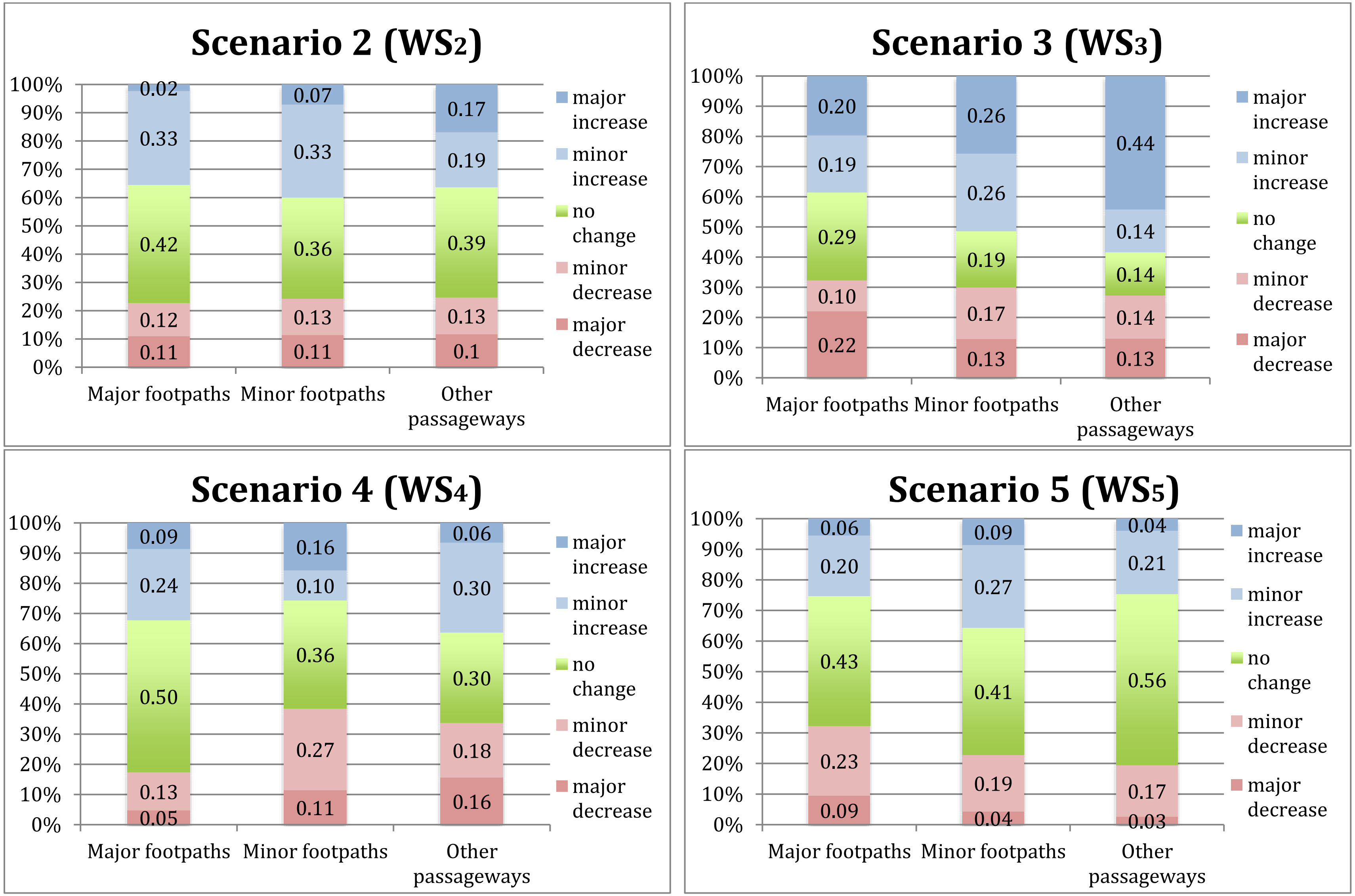

Figure 5 Summary of the changes in walkability scenarios (WS_2 to WS_5) compare to the reference scenario (WS_1) by types of footpath

Table 1 Major environmental audit tools reviewed

Name of tool	Study area	Author(s)	Objective of tool	Specifications of tool	Comment
Systematic Pedestrian and Cycling Environmental Scan (SPACES)	Perth, Australia	Pikora et al. (2003)	To measure the physical environmental factors that may influence walking and cycling in local neighborhoods	71 items in four dimensions (functional, safety, aesthetics, destinations)	Not only use audit data, but also GIS and desktop method
Walking Suitability Assessment Form (WSAF)	North Carolina, USA	Emery, Crump, & Bors (2003)	To assess the suitability of sidewalks for walking and roads for cycling.	10 items for walkability, 27 items for bikability	Focus more on bikability, few items on amenities and destinations
Path Environment Audit Tool (PEAT)	Massachusetts, USA	Troped et al. (2006)	To develop a reliable measures of trail characteristics	40 items in three dimensions (design features, amenities, maintenance /aesthetics)	Focus on trails in parks and outdoor recreation areas, more design and maintenance items
Pedestrian Environmental Data Scan (PEDS)	University of Maryland, College Park, USA	Clifton, Smith, & Rodriguez (2007)	To develop a tool to capture a range of elements of the built and natural environment efficiently and reliably	40 questions and 83 measures in five groups (subjective assessment, environment, pedestrian facility, road attributes, walking/cycling environment)	Few items on land use and destinations Include subjective assessment items
Active Neighbourhood Checklist (ANC)	St. Louis, USA	Hoehner, Ivy, Ramirez, Handy, & Brownson (2007)	To assess major street-level features of the neighborhood environment that are related to physical activity behavior	40 items in five major areas (land use, public transit stops, street characteristics, quality of the environment for a pedestrian, and places to walk and bicycle)	Few items concerning safety and aesthetics
Environment in Asia Scan Tool (EAST-HK)	Hong Kong	Cerin et al. (2011)	To objectively measure aspects of the neighbourhood environment assumed to affect walking in Hong Kong and other ultra-	91 items in four dimensions (functionality, safety, aesthetics, destinations)	Extensive selection of items on destinations tailored for local context

			dense Asian cities		
Microscale Audit of Pedestrian Streetscapes (MAPS)	San Diego, Seattle, and the Baltimore metropolitan areas, USA	Millstein et al. (2013)	To develop a tool and create summary scores that can be used to assess detailed attributes of the built environment relevant to physical activity	160 items in four sections (overall route, street segments, crossings, and cul-de-sacs)	Extensive selection of items and structured scoring system in creating summary scores
China Urban Built Environment Scan Tool (CUBEST)	Hangzhou, China	Su et al. (2014)	To design an assessment tool of urban built environment related to adult physical activity in China	41 items in six dimensions (residential density, street connectivity, accessibility, sidewalk quality, bike lane quality, aesthetics)	More focus on bikability, and accessibility to various destinations, few items on amenities and subjective assessment
Irvine–Minnesota Inventory-China (IMI-C)	Shanghai & Hangzhou, China	Alfonzo et al. (2014)	To objectively measure “micro-scale” built environment features that may be tied to walking and bicycling	286 items in 11 dimensions (density, proximity, connectivity, form, parks and public space, pedestrian infrastructure, bike infrastructure, personal safety, traffic safety, aesthetics, recreational facilities)	Extensive selection of items, but the detailed measurement items used in IMI-C is not available
China Urban Rail Walking Access Scan Tool (CURWAST)	Nanchang, China	Sun, Webster, & Chiaradia (2017)	To measure the walking environments of access routes to urban rail transit	67 items in seven dimensions (building density, land use diversity, elements on sidewalk, design, road beside sidewalk, transferability, subjective assessment)	Target specifically on access routes to rail transit, few items on footpath condition and maintenance

Table 2 Major qualities (in bold), sub-qualities (in italics), constructs (underlined) and measurement items (in the notes) used in this study

Land use and destinations (LAND) (15)	**Aesthetics (AEST) (6)**	**Footpath design and condition (PATH) (13)**
Residential land use (4) [a]	*Surrounding environment*	*Footpath design*
Destinations	Streetscape features (2) [k]	Steepness (1)
Food related (3) [b]	Tree coverage (1)	Width (1)
Commercial / Retail (3) [c]	*Views*	Protection from weather (1)
Leisure related (2) [d]	Sightlines (1)	*Footpath condition*
Office / Institutional (2) [e]	Horizontal sightlines (1)	Trip hazards (1)
Transport related (1) [f]	Proportion of sky (1)	Physical obstructions (4) [o]
		Temporary obstructions (5) [p]

Safety (SAFE) (18)	**Amenities (AMEN) (11)**	**Subjective assessment and experience (SUBJ) (8)**
Traffic safety	*Pedestrian amenities*	*Subjective assessment*
Roads beside footpath (1)	Street lights (1)	Sufficient illumination (1)
1 or 2-way street (1)	Amenities (3) [l]	Feel safe (1)
Ingress on segment (1)	*Amenities for special needs*	Feel stressful
Parking spaces on footpath (1)	Tactile paving (1)	Feel attractive
Presence of buffers (4) [g]	Problems with paving (4) [m]	*Sensory experience*
Presence of other users (2) [h]	Way-finding aids (2) [n]	Any unpleasant smell (1)
Personal safety		Any unpleasant sound (1)
Physical disorder (3) [i]		Volume of sound (1)
Social disorder (3) [j]		Observable air pollution (1)
Police office/stand (1)		$PM_{2.5}$ (1)
Police officer (1)		PM_{10} (1)

Notes:

The numbers in brackets after each construct is the number of measurement items remained in the final audit tool after the reliability tests

[a]: detached or semi-detached houses (1-3 stories); residential buildings 4-6 stories; 7-13 stories; 14-20 stories; over 20 stories

[b]: Food: supermarket/fresh food market; restaurant; 24hr convenient store

[c]: Commercial/Retail: shopping mall; bank; hotel; other retail shops
[d]: Leisure: plaza; playground/park; sports ground/ball court
[e]: Office/Institutional: government buildings; office buildings
[f]: Transport: car park; bus stop
[g]: railings; bollards; trees; planters
[h]: cyclists; electric scooter/bike users; motorcycles; mini-trucks
[i]: graffiti/flyer; abandoned building/land; noticeable litter/dog faeces
[j]: street fouling; idlers/gambling on street
[k]: sculpture; fountain; landscape garden; bodies of water; greenery
[l]: trash bins; benches/sitting spaces; bicycle rack; public toilets
[m]: paving worn out; paving misalignment; inappropriate design; blockage on paving
[n]: public transport map; neighbourhood map; local destination sign; metro station sign
[o]: rubbish collection point; electric switch box; stores/kiosks; stairs/steps
[p]: parked cars/bikes; street vendor; eating/catering area; other commercial activities; construction waste

Table 3 Overview of intra-rater reliability results by walkability qualities

Walkability Qualities	No. of items	Kappa / ICC [a] Substantial - Perfect	Moderate	Fair - Poor	Items with insufficient variability	Percentage Agreement [b] High	Moderate	Low	Items with insufficient variability
Land use and destinations	19	15	0	0	4	16	0	0	3
Safety	22	13	3	5	1	15	3	3	1
Aesthetics	9	7	0	0	2	4	3	0	2
Amenities	14	8	1	1	4	12	0	0	2
Footpath design and condition	13	9	3	1	0	11	2	0	0
Subjective assessment and experience	10	0	5	5	0	2	6	2	0
Total (percentage)	87	52 (59.77%)	12 (13.79%)	12 (13.79%)	11 (12.64%)	60 (68.97%)	14 (16.09%)	5 (5.75%)	8 (9.20%)

[a]: Substantial - Perfect: >0.6; Moderate: = 0.4 – 0.6; Poor - Fair: <0.4.

[b]: High: ≥ 75%; Moderate: 60 – 74%; Low: <60%

Table 4 Overview of inter-rater reliability results by walkability qualities

Walkability Qualities	No. of items	Kappa / ICC [a] Substantial - Perfect	Moderate	Fair - Poor	Insufficient variability	Percentage Agreement [b] High	Moderate	Low	Insufficient variability
Land use and destinations	19	12	0	0	7	17	0	0	2
Safety	22	20	1	0	1	20	1	0	1
Aesthetics	9	5	1	0	3	5	2	1	1
Amenities	14	9	1	0	4	12	0	0	2
Footpath design and condition	13	10	1	0	2	13	0	0	0

Subjective assessment and experience	10	4	5	1	0	6	4	0	0
Total (percentage)	87	60 (68.97%)	9 (10.34%)	1 (1.15%)	17 (19.54%)	60 (68.97%)	9 (10.34%)	1 (1.15%)	17 (19.54%)

[a]: Substantial - Perfect: >0.6; Moderate: = 0.4 – 0.6; Poor - Fair: <0.4.

[b]: High: ≥ 75%; Moderate: 60 – 74%; Low: <60%

Table 5 Descriptive statistics of five walkability scenarios

	WS_1	**WS_2**	**WS_3**	**WS_4**	**WS_5**
Median	.488	.034	.215	.228	.186
Mean	.480	.114	.271	.259	.246
(by footpath types)					
Major footpaths	.570	.162	.322	.356	.304
Minor footpaths	.491	.125	.296	.254	.263
Other passageways	.321	.026	.162	.105	.134
Skewness	.126	2.336	1.123	.664	1.191
Percentiles					
25	.289	.001	.088	.058	.079
50	.488	.034	.215	.228	.186
75	.641	.125	.385	.430	.346

Table 6 Compare the mean walkability indices (and rankings) of the five scenarios by neighbourhoods

	WS_1	**WS_2**	**WS_3**	**WS_4**	**WS_5**
Inner-High (IH)	.438 (4)	.074 (4)	.257 (4)	.202 (4)	.192 (4)
Inner-Low (IL)	.512 (2)	.117 (2)	.258 (3)	.296 (2)	.286 (2)
Outer-High (OH)	.483 (3)	.116 (3)	.265 (2)	.268 (3)	.260 (3)
Outer-Low (OL)	.538 (1)	.216 (1)	.335 (1)	.346 (1)	.310 (1)
Test stat.	2.459	6.076	1.286	5.063	4.946
p value	.063	.001	.280	.002	.002
Sig. differences	IH-IL, IH-OL	IH-OL, IL-OL, OH-OL	-	IH-IL, IH-OL	IH-IL, IH-OH, IH-OL

Table 7 The changes in relative walkability of footpaths in WS_2 to WS_5

Percentage of footpaths	WS_2	WS_3	WS_4	WS_5
Major decrease	11.3%	17.2%	9.5%	6.2%
Minor decrease	12.4%	13.1%	17.9%	20.1%
No change	39.4%	22.3%	40.9%	46.0%
Minor increase	29.2%	19.3%	21.9%	21.9%
Major increase	7.7%	28.1%	9.8%	5.8%

Appendix 1 Major walkability qualities and measurement items in environmental audit tools

Walkability qualities	Description of features	Examples of measurement items in existing studies	Newly added and modified items developed in this study
Land use and destinations	This quality considers both the origins and destinations of neighbourhood level walking trips, which captures the residential development density and presence of various commercial and non-commercial destinations.	● Residential density (Malecki et al., 2014; Su et al., 2014; Cerin et al., 2011) ● Building density (Sun et al., 2017) ● Various destinations (Su et al., 2014; Sun et al., 2017; Cerin et al., 2011; Troped et al., 2006; Millstein et al., 2013; Pikora et al., 2003)	● Destinations were selected to focus on five major types (food/restaurants, commercial/retail, leisure, office, transport) [1, 2, 3]
Safety	This quality covers all design features that are directly or indirectly associate with people sense of safety, including both traffic and personal safety.	● Street network (Sun et al., 2017; Troped et al., 2006; Millstein et al., 2013; Cerin et al., 2011; Pikora et al., 2003) ● Litter and Graffiti (Su et al., 2014; Cerin et al., 2011; Millstein et al., 2013; Malecki et al., 2014) ● Buffers between road and footpath (Sun et al., 2017; Cerin et al., 2011; Troped et al., 2006; Millstein et al., 2013; Malecki et al., 2014) ● Signs of crime/disorder (Cerin et al., 2011; Troped et al., 2006; Millstein et al., 2013) ● Aggressive drivers (Cerin et al., 2011) ● Signage for drivers (Millstein et al., 2013) ● Surveillance (Pikora et al., 2003)	● Presence of other users on footpath [1, 2] ● Presence of police office / stand [1, 2] ● Presence of police officers [1, 2]
Aesthetics	This quality consists of features that capture the aesthetic qualities of the walking environment, including streetscape features and views from the footpath.	● Natural sights (Su et al., 2014; Cerin et al., 2011; Malecki et al., 2014) ● Cultural landscape (Su et al., 2014) ● Trees (Sun et al., 2017; Millstein et al., 2013; Pikora et al., 2003) ● Attractive buildings (Cerin et al., 2011; Millstein et al., 2013; Pikora et al., 2003; Malecki et al., 2014) ● Sightline (Troped et al., 2006) ● Public art (Millstein et al., 2013) ● Interesting views (Pikora et al., 2003)	● Proportion of sky [2, 3] ● Horizontal sightline [2, 3]
Amenities	This quality comprises of design	● Lighting (Sun et al., 2017; Millstein et al., 2013;	● Way-finding aids [1, 2]

	features that can facilitate safe and efficient movement of pedestrians. Including amenities for the general pedestrians and amenities for people with special needs.	Pikora et al., 2003) ● Benches (Sun et al., 2017; Malecki et al., 2014) ● Trash bins (Sun et al., 2017; Millstein et al., 2013; Malecki et al., 2014) ● Public telephone (Millstein et al., 2013) ● Drinking fountains (Millstein et al., 2013)	● Tactile paving [1, 2, 3] ● Problems with tactile paving [1, 2, 3]
Footpath design and condition	This quality captures the functional characteristics (including steepness, effective width) and the condition of footpath (including trip hazards, physical and temporary obstructions).	● Footpath width (Su et al., 2014; Pikora et al., 2003) ● Walking barriers (Sun et al., 2017; Cerin et al., 2011) ● Well-maintained footpath (Cerin et al., 2011) ● Steepness of footpath (Cerin et al., 2011; Pikora et al., 2003) ● Footpath surface (Pikora et al., 2003) ● Obstructions on footpath (Pikora et al., 2003)	● Revised and new items on temporary obstructions [1, 2]
Subjective assessment and experience	This quality relates to the subjective assessment and the sensory experience associated with the walking environment.	● Attractive for walking (Sun et al., 2017; Pikora et al., 2003) ● Difficult for walking (Pikora et al., 2003) ● Feels safety for walking (Sun et al., 2017) ● Noise pollution (Cerin et al., 2011) ● Air pollution (Cerin et al., 2011)	● Sufficient illumination [1, 2, 3] ● Pleasant smell [1, 2] ● Pleasant sound [2] ● Feel stressful [2] ● Volume of sound [1, 2, 3] ● $PM_{2.5}$ [2, 3] ● PM_{10} [2, 3]

Notes: [1] Based on local residents' comments; [2] Based on lead author's fieldwork observations; [3] Based on literature review

Appendix 2

Environmental audit tool

Auditor ID ________ Name ____________
Neighborhood ________________________
Date____________________________________
Day: Mon/Tue/Wed/Thur/Fri/Sat/Sun
Segment No______________________________
Start Time___________________________

Section: Land use and destinations

1. What type of residential uses can be observed? *(Check all that apply)*
   - ☐ Detached or semi-detached houses (1-3 stories)
   - ☐ Residential buildings (4-6 stories)
   - ☐ Residential buildings (7-13 stories)
   - ☐ Residential buildings (14-20 stories)
   - ☐ Residential buildings (over 20 stories)

2. What type of land uses can be observed? *(Check all that apply)*
   - ☐ Supermarket / Fresh food market
   - ☐ Restaurant
   - ☐ 24hr convenient store
   - ☐ Shopping mall/department store
   - ☐ Bank/Financial institution
   - ☐ Other retail stores
   - ☐ Hotel
   - ☐ Plazas
   - ☐ Playground / Park
   - ☐ Sports ground / ball court
   - ☐ Government buildings
   - ☐ Office buildings
   - ☐ Bus stop
   - ☐ Multi-storey car park

Section: Safety

1. Which of the following types best describe this road?
   - ☐ Road with separated footpath
   - ☐ Road without separated footpath
   - ☐ Pedestrian only road
   - ☐ Internal road mixed with car park

2. Is this road 1-way or 2-way?
   ☐ 1-way ☐ 2-way ☐ unclear

3. Are there any driveways (ingress / egress) on the segment?
   ☐ Yes ☐ No

4. Are there any parking spaces on footpath? ☐ Yes ☐ No

5. Are there any buffers between road and footpath? *(Check all that apply)*
   ☐ Railings ☐ Bollards
   ☐ Trees ☐ Planters

6. Are there other users on the footpath? (On pedestrian section if cycle lane is present) *(Check all that apply)*
   - ☐ Cyclists
   - ☐ User of e-bike / electric scooter
   - ☐ Motorcycles
   - ☐ Mini-truck
   - ☐ Others ___________________________

7. Which of the following physical disorders are present? *(Check all that apply)*
   - ☐ Graffiti / commercial flyer
   - ☐ Abandoned building / Vacant land
   - ☐ Noticeable litter / dog faeces

8. Which of the following social disorders are present? *(Check all that apply)*
   - ☐ Street fouling
   - ☐ Idlers / People gambling on street

9. Are there any police booth or security stand along this segment?
   a) ☐ Yes ☐ No
   If Yes, can you see any police in it?
   b) ☐ Yes ☐ No

Section: Footpath design and condition

1. Steepness of footpath
   ☐ Nearly flat ☐ Slightly sloped
   ☐ Strongly sloped that affect balance

2. What is the average effective width of footpath?
   ☐ less than 1m ☐ 1m – <2m
   ☐ 2m – 3m ☐ more than 3m

3. To what extent the road segment is protected from inclement weather? *(e.g. building hangover, shelter, covered walkway)*
   ☐ 0% ☐ 1-25% ☐26-50%
   ☐ 51-75% ☐ 76-100%

4. Are there poorly maintained sections of the footpath that constitute trip hazards? (e.g. heaves, misalignment, cracks, overgrowth)
   ☐ None ☐ Some ☐ Ample

5. Are there any of the following physical obstructions along the footpath? *(Check all that apply)*
   - ☐ Rubbish collection point
   - ☐ Electricity switch box
   - ☐ Store / Kiosk
   - ☐ Stairs / Steps / Slopes

6. Are there any of the following temporary obstructions along the footpath? *(Check all that apply)*
   - ☐ Parked cars/bikes/motorcycles
   - ☐ Street vendor
   - ☐ Outdoor eating/catering area
   - ☐ Other commercial activities
   - ☐ Construction waste

Section: Aesthetics

1. Can you observe any following hardscape features *(Check all that apply)*
   ☐ Sculptures ☐ Fountains
   ☐ Landscape garden ☐ Bodies of water
   ☐ Greenery view

2. What is the percentage of tree coverage along the segment?
   ☐ 0% ☐ 1-25% ☐26-50%

☐ 51-75% ☐ 76-100%

3. Can you have clear sightlines (both directions) along this segment of footpath?
☐ Good (can see the whole segment)
☐ Fair (can see part of this segment)
☐ Poor (some blockage of this segment)

4. Can you see both sides of the footpath (horizontally) without any obstruction, like tall buildings, walls, etc.
☐ Continuous lateral visibility
☐ Moderate lateral visibility
☐ No lateral visibility

5. From the middle of the segment, what proportion of sky can you see?
☐ 0% ☐ 1-25% ☐26-50%
☐ 51-75% ☐ 76-100%

Section: Amenities

1. Are street lights installed along the segment?
☐ None ☐ Some ☐ Ample

2. Can you observe these amenities? *(Check all that apply)*
☐ Trash bins
☐ Benches or other sitting spaces
☐ Bicycle rack
☐ Public toilets
☐ Others ____________________________

3. What is the percentage of tactile paving along the segment? (For guiding purpose)
☐ 0% ☐ 1-25% ☐26-50%
☐ 51-75% ☐ 76-100%

4. Are there any problems associated with the tactile paving for visually impaired people?
☐ Paving worn out
☐ Misalignment of paving
☐ Inappropriate design
☐ Paving blocked by other things

5. Are there way-finding aids available in this segment? *(Check all that apply)*
☐ Public transport route map
☐ Neighbourhood area map
☐ Directional sign (local destination)
☐ Directional sign (MTR station)
☐ Others ____________________________

Section: Subjective assessment and experience

1. Is there sufficient illumination to see the path clearly along the segment?
☐ Insufficient ☐ Fair ☐ Sufficient

2. How safe do you feel when you walk along the segment?
☐ Safe ☐ Neutral ☐ Unsafe

3. Do you feel stressful when you walk along the segment?
☐ Relaxed ☐ Neutral ☐ Stressful

4. How attractive visually is this segment of footpath?
☐ Attractive ☐ Neutral ☐ Unattractive

5. Can you smell any unpleasant smell along the segment?
☐ Yes ☐ No

6. What can you hear along the segment?

a) Pleasantness of sound
☐ Some pleasant sound
☐ Little or no sound
☐ Some unpleasant sound

b) Measure the volume of sound
________________________ (dB)

7. Is there any smog or observable air pollution?
☐ Yes ☐ No

8. Measure the air quality for PM2.5 and PM10.
a) PM 2.5____________
b) PM 10 ____________

Other special observations:

End Time ____________________________