Doctoral Dissertation

An expert-informed audit tool for activity-friendly parks in dense urban areas

LUO Yufeng

Supervisor　KOOHSARI Mohammadjavad

Graduate School of Advanced Science and Technology
Japan Advanced Institute of Science and Technology
(Knowledge Science)

September 2025

Abstract

The global prevalence of physical inactivity and sedentary behaviour has become a pressing public health concern, contributing significantly to the burden of non-communicable diseases such as cardiovascular disease, type 2 diabetes, obesity, and certain types of cancer. Public open spaces are recognised as an essential component of the built environment that supports physical activity, promotes active lifestyles, and reduces risk factors for non-communicable diseases. However, rapid urbanisation in Asia has led to increasingly dense urban environments characterised by limited open space, spatial fragmentation, and intense competition for land use. Existing auditing tools have primarily been developed in low-density urban settings in the West, resulting in considerable gaps in their applicability to dense urban contexts, their cultural adaptability to Asian cities, and their usability across diverse user groups. These limitations restrict both the application and scientific evaluation of urban environments in different global contexts. This thesis addresses these challenges by developing and testing a park audit tool tailored specifically for high-density urban areas in Asia.

This research presents the development, validation, and remote adaptation of the dense urban park audit tool, with a focus on supporting park-related physical activity in dense urban settings. This study was conducted in Tokyo, Japan, a representative dense Asian city with constrained Public open space. Employing a multi-phase, mixed-methods design, the study involved: (1) the development of the dense urban park audit tool through systematic literature review and expert consensus; (2) field validation in selected urban parks; and (3) remote adaptation using publicly accessible virtual imagery.

Dense urban park audit tool was constructed through a systematic review of existing park audit tools and the construction of park environmental attributes that influence physical activity. Expert opinions were gathered through a fuzzy Delphi consultation involving interdisciplinary experts and researchers to identify and prioritise key park attributes. Dense urban park audit tool comprises six sections—park base information, park surroundings and accessibility, activity areas, facilities and amenities, aesthetics, and safety—measured via a series of quantifiable and clearly defined items. Pilot testing and iterative revisions ensured item clarity and feasibility. Field validation in 25 Tokyo parks assessed inter-rater reliability using Cohen's kappa and percent agreement, and construct validity against a gold standard (trainer ratings). Results showed that 91.1% of items achieved kappa values above 0.4, indicating at least moderate agreement, while 95.9% surpassed 70% agreement. Overall dimension-level validity was confirmed with 87.5% agreement, supporting audit tool's reliability and appropriateness for dense urban contexts.

Recognising the growing need for low-cost, scalable environmental assessment methods, particularly when logistical constraints limit on-site auditing across large or dispersed samples, this study introduced a remote version of dense urban park audit tool. Using Google Earth Pro as the primary data source, remote version of dense urban park audit tool was tested across 53 parks in Tokyo, with a subset (n = 25) also assessed on-site for comparative validation. Remote version of dense urban park audit tool demonstrated high inter-rater reliability, with 89% of items showing moderate to almost perfect agreement. Convergent validity, measured via intraclass correlation coefficient (ICC), indicated a strong correlation between remote and on-site assessments (ICC = 0.73). While virtual audits cannot evaluate transient or sensory attributes such as litter or graffiti, they offer significant advantages in replicability, time efficiency, and cost savings.

This thesis demonstrates a rigorous, scientifically sound and replicable research pathway for developing a park audit tool that addresses the specific challenges of dense urban environments. By bridging gaps in existing literature—inadequate applicability in dense urban contexts, insufficient adaptability to Asian cultures, and limited diversity of intended users—this research advances the scientific understanding of the link between built environment attributes and physical activity. Both on-site and remove version of dense urban park audit tool offer practical, scalable solutions for urban planners, public health professionals, and researchers aiming to enhance park environments to promote active living. In doing so, this study contributes meaningfully to the fields of urban health, built environment research, and methodological innovation.

Keywords: science-based urban design; observational audit; virtual assessment; public open space; neighbourhood design; physical activity; healthy cities

Acknowledgement

I would like to express my deepest gratitude to everyone who has supported and helped me throughout the completion of this dissertation.

First and foremost, my heartfelt thanks go to my supervisor, Professor Mohammadjavad Koohsari, for his invaluable guidance, continuous support, and unwavering encouragement throughout my PhD journey. Reflecting back to October 2022, when we both joined JAIST in different roles, I had the great honor of becoming his first PhD student. It has been a privilege to witness and contribute to the founding and growth of the Urban Design Science for Health Lab. During my doctoral studies, Professor Koohsari consistently provided insightful and rigorous academic guidance. Beyond research, his patience, understanding, and support in daily life have deeply touched me. He has not only been my academic mentor but also a trusted and dependable companion. I am sincerely and profoundly grateful to him.

I would also like to extend my sincere appreciation to the esteemed researchers who contributed to my PhD research: Professor Yasunaga, Professor Kaczynski, Professor Hanibuchi, Professor McCormack, and Professor Oka. Your insightful academic suggestions during manuscript preparation and journal revisions were instrumental in enhancing the quality and rigor of my work. I am truly thankful for your expertise and generous support.

I would like to express my sincere gratitude to all the distinguished professors who participated in my thesis defence. Your constructive feedback from diverse perspectives has been invaluable in helping me refine and strengthen both my research and dissertation. My heartfelt thanks go to my internal examiners, Professor Kim, Professor Huynh, and Professor Yuizono, as well as to my external examiner, Professor Yasunaga, for your thoughtful evaluations and generous support.

My thanks also go to my lab members, Li Jiuling and Zhao Jing, for their assistance and cooperation in data collection and processing. Your contributions played a crucial role in the smooth progress of my research. I am also deeply grateful to my friends at JAIST. In times of academic stress or personal hardship while studying abroad, your understanding and encouragement gave me the strength to persevere. Thank you for your genuine friendship and selfless support.

To my family, I owe a debt of gratitude beyond words. Your unconditional love and enduring support have been the foundation of my 23-year academic journey, from primary school to this doctoral milestone. As my studies led me further from home, you remained my constant, offering quiet strength, deep understanding, and boundless patience. This steadfast familial love has been the greatest source of strength in my life and studies. It is because of you that I was able to keep going. Your love and belief in me are gifts I will cherish forever. To my partner, Chen, thank you from the bottom of my heart for wholeheartedly supporting my decision to pursue a PhD, even though it meant enduring long periods of separation and many difficult realities. Throughout this long and challenging journey, your unwavering faith and gentle patience carried me through.

Publications

Journal Papers: The following peer-reviewed publications were directly derived from the research conducted in this doctoral thesis.

[1] **Luo, Y.**, Motomura, M., Zhao, J., Hanibuchi, T., Nakaya, T., Shibata, A., … Koohsari, M. J. (2024). Developing and testing an audit tool for activity-friendly parks in dense urban areas of Asia. *Cities & Health* (Q1 Journal), 1–13. https://doi.org/10.1080/23748834.2024.2426948

[2] **Luo, Y.**, Kaczynski, A. T., Li, J., Motomura, M., Zhao, J., Hanibuchi, T., … Koohsari, M. J. (2025). Redesigning urban parks for active living in dense urban areas: a remote audit approach. *International Journal of Environmental Health Research* (Q2 Journal), 1–11. https://doi.org/10.1080/09603123.2025.2469650

International Conferences:

[1] International Symposium on the Sport and Recreation Sustainable Development Goals (SDGs) December 8-10, 2023. National Taiwan Sport University, Taiwan, China
Paper presentation: Developing an Audit Tool for Activity-friendly Parks in Dense Urban Areas (Award: Outstanding poster)

Contents

List of Figures

List of Tables

Chapter 1 Introduction

1.1 Public open spaces

1.1.1 Definitions of public open spaces

Public open spaces are an essential part of the urban environment and are widely recognised as an important urban infrastructure which promotes health, improves social interaction and improves the quality of the environment [1]. In urban planning studies, the term public open space is defined as managed, even if it is time-controlled, open spaces that are freely accessible [2]. The conceptual characteristics of public open space are: (1) accessibility - accessible to all individuals without any entry fees or restrictions; (2) organisational management - usually managed and maintained by government agencies, municipal authorities, community organisations or authorised bodies; (3) multifunctionality - supports a wide range of purposes, such as physical activity, social interaction and the promotion of community culture; and (4) environmental benefits - contributes to improving air quality and mitigating the effects of urban heat islands [3, 4].

1.1.2 Categories of public open spaces

Based on function and spatial scale, public open space can be divided into the following types: (1) Parks. Urban green spaces that are accessible to the public and primarily intended for socialisation, recreation, and physical activity [5]; (2) Plazas. Open spaces in the city centre, mainly used for gathering, traffic distribution, public visits, rest, and commercial services [6, 7]; (3) Trails and greenways. Linear green spaces suitable for public walking, cycling and other slow-moving recreational purposes [8]; (4) Waterfront spaces. Spaces accessible to the public where water and urban land connect, including three parts: water body, water boundary, and land area [9]. These spaces not only provide recreational, social, and ecological functions, but also play an important role in promoting physical activity and enhancing the health of residents [4, 10].

1.1.3 Definitions of parks

Parks represent one of the most typical and prevalent forms of public open space and are considered a component of urban infrastructure [11]. They fulfil multiple essential functions within urban environments. Firstly, parks play a critical role in promoting public health by encouraging physical activity, which in turn helps to reduce the risk of non-communicable diseases such as obesity and cardiovascular conditions [12]. Secondly, they serve as important venues for social interaction, offering spaces for community activities that help strengthen

neighbourhood ties and enhance social cohesion [13]. Thirdly, parks contribute significantly to urban ecosystems by providing environmental services such as improving air quality through increased vegetation, regulating urban temperature, and supporting biodiversity [14, 15]. Lastly, parks generate economic value by increasing nearby property prices, attracting commercial and tourism activities, and thereby contributing to local economic development [16]. According to their functional scope and intended purpose, parks can be categorised into several types, including urban parks, community parks, national nature parks, and thematic parks.

1.1.4 Parks and health promotion

High-quality parks play a vital role in encouraging and supporting residents to engage in regular physical activity, such as walking, jogging, cycling, and other forms of exercise that promote healthy lifestyles. Consistent participation in these activities contributes to the prevention and mitigation of non-communicable diseases, including obesity, cardiovascular diseases, and type 2 diabetes [17]. Previous research has examined various park-related factors that support physical activity, which can be summarised into the following dimensions:

Park surroundings. Park surroundings refer to the physical, social, and environmental characteristics at the boundary of a park and its adjacent neighbourhood [18]. This includes elements such as street connectivity, pedestrian and cycling infrastructure, land use patterns, building density, green space connectivity, traffic conditions, and the socio-economic profile of surrounding communities. Although parks are discrete spatial entities, they are deeply embedded in their surrounding urban fabric. These surrounding features significantly influence the accessibility, perceived safety, and overall utilisation of the park, thereby shaping its impact on residents' physical activity and health outcomes [19].

Park accessibility. Park accessibility typically refers to the ease with which individuals can reach parks, encompassing multiple modes of transport such as walking, cycling, public transit, and private vehicles [20]. This concept extends beyond simple physical distance (e.g., straight-line or road network distances) to include factors such as infrastructure quality (e.g., continuity of footpaths and bike lanes), safety (e.g., pedestrian crossings and traffic control), affordability (e.g., transport costs), and social equity (e.g., equal access for different socio-economic groups) [21]. Accessibility is a critical determinant of park use and frequency of physical activity, as it shapes whether residents can conveniently and safely access parks with minimal cost and effort.

Park activity areas. Activity areas within parks are specifically designed spaces intended to support a variety of physical and recreational activities [22]. These may include sports fields, children’s playgrounds, fitness stations, running tracks, green lawns, multi-purpose plazas, and picnic or leisure zones. By providing diverse spatial settings and facilities, activity areas accommodate varying needs across age groups, physical abilities, and individual preferences [23]. The design and quality of these areas are directly associated with increased park usage and higher levels of physical activity among residents. Well-designed activity spaces can significantly encourage outdoor engagement, continuity of movement, and the adoption of

healthier lifestyles.

Park facilities and amenities. Park facilities and amenities refer to the infrastructure and accessory equipment provided in parks to support physical activity, recreation, social interaction, and environmental sustainability. Park facilities and amenities include benches, barrier-free access, drinking fountains, restrooms, changing rooms, shelters, and parking. Well-established and high-quality facilities and amenities not only provide a convenient and comfortable environment for park users, but also enhance the overall attractiveness of the parks, which can directly facilitate physical activity [24].

Park aesthetics and attractiveness. Park aesthetics and attractiveness are concerned with the visual, sensory, and experiential qualities of the park environment [25]. These include aspects such as landscape design, the extent of green space coverage, water features, artistic elements, and the overall condition and maintenance of the park. A visually pleasing and well-maintained park environment significantly contributes to its appeal, drawing more visitors and encouraging regular use for leisure and physical activity.

Park safety and incivilities. Park safety encompasses both the physical and psychological aspects of security within the park environment [26]. This includes crime prevention measures, the structural safety of facilities, and the visibility and surveillance of public spaces. High levels of safety are typically characterised by low crime rates, adequate lighting, clean and intact infrastructure, and effective monitoring systems, all of which contribute to reducing risks associated with park use. Conversely, incivilities refer to disruptive or damaging behaviours and environmental conditions that reduce park enjoyment. Examples include littering, vandalism, graffiti, fighting, smoking, alcohol consumption, and noise pollution [26]. These issues negatively affect user experience and may deter individuals from using parks, thus undermining the park's health-promoting potential.

1.1.5 Summary

A systematic assessment of park environmental characteristics that support physical activity is essential for optimising their design and management to promote more active lifestyles. With the continued acceleration of urbanisation, identifying scientific strategies for the renewal and enhancement of parks to maximise their health benefits has become a critical area of research.

1.2 Physical activity

1.2.1 Definitions of physical activity

Physical activity is commonly defined as any bodily movement produced by the contraction of skeletal muscles that results in energy expenditure [27]. According to the World Health Organization [28], physical activity encompasses “any bodily movement produced by

skeletal muscles that requires energy expenditure." This definition underscores the complexity and multidimensional nature of physical activity, which includes a broad spectrum of movement behaviours. These can occur in various life domains, including household activities (e.g., yard work, domestic cleaning, and caregiving), transport-related activities (e.g., walking or cycling to work), occupational activities, and leisure-time activities (e.g., sports or planned exercise, dancing, swimming).

Engagement in physical activity contributes to an individual's total energy expenditure, which comprises three key components: the basal metabolic rate, the thermic effect of food, and energy expended during physical activity (Figure 1.1). In contrast, physical inactivity refers to a condition in which minimal physical movement occurs, and energy expenditure remains close to the resting metabolic rate. This sedentary state is increasingly associated with a higher risk of non-communicable diseases and reduced quality of life [28].

Total energy expenditure =

Basal metabolic rate + Thermic effect of food + Physical activity

Figure 1.1. The components of total energy expenditure

1.2.2 Categories of physical activity

Physical activity can be classified based on various criteria, most commonly intensity, frequency, and duration [28]. These categories provide a structured framework for researchers, policymakers, and health professionals to examine how different forms of physical activity contribute to health promotion, disease prevention, and physical performance enhancement.

Intensity. Intensity refers to the level of effort required to perform a physical activity and the corresponding rate of energy expenditure. It is commonly quantified using the unit Metabolic Equivalent of Task (MET) which represents the ratio of energy expended during a specific activity to that expended at rest [28]. One MET is defined as the energy cost of sitting quietly. According to the World Health Organization [28], physical activity intensity can be categorised into three levels based on MET values: Light-intensity Physical Activity (LPA), Moderate-intensity Physical Activity (MPA), and Vigorous-intensity Physical Activity (VPA). These categories are illustrated in Figure 1.2, while Table 1.1 provides examples of common physical activities and their estimated energy expenditures across intensity levels [28].

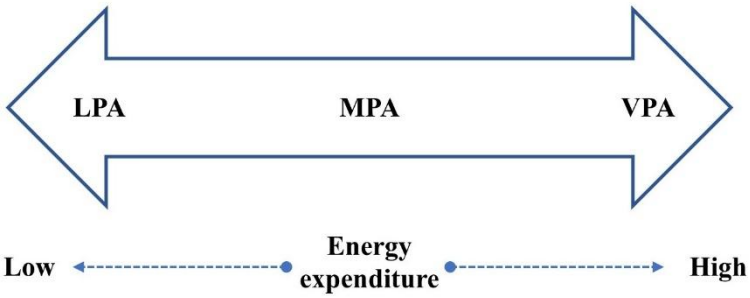

Figure 1.2. The intensity of physical activity

- LPA (1.5-3 METs). These activities involve minimal physical effort and result in only a slight increase in heart rate and respiration. They are typically non-strenuous and easy to sustain for long periods. Common examples include light housework, slow-paced walking, bathing, and gentle stretching.
- MPA (3-6 METs): MPA leads to noticeable increases in breathing and heart rate, accompanied by light perspiration, yet remains comfortable enough to allow for conversation. Such activities are sustainable over time. Examples include brisk walking, cycling at a moderate pace, and recreational swimming.
- VPA (greater than 6 METs): VPA involves high physical exertion that significantly elevates heart rate and breathing, often resulting in heavy sweating and reduced ability to speak. These activities are demanding and typically not sustained for long durations without rest. Examples include fast running, high-intensity interval training (HIIT), and competitive sports.

Table 1.1. the intensity and energy expenditure of physical activities.

Activity	Intensity	METs	Energy expenditure (kcal)
Cleaning and dusting	Light intensity	2.5	75
Strolling	Light intensity	2.5	75
Walking	Light intensity	2.5	75
Vacuum cleaning	Moderate intensity	3.5	105
Badminton	Moderate intensity	4.5	135
Tennis	Moderate intensity	5.0	150
Brisk walking	Moderate intensity	5.0	150
Cycling	Moderate intensity	6.0	180
Swimming	Moderate intensity	6.0	180
Competitive swimming	Vigorous intensity	8.0	240
Competitive tennis	Vigorous intensity	8.0	240
Fast running	Vigorous intensity	13.5	404

Frequency. The frequency of physical activity refers to the number of sessions performed within a defined time frame, typically measured on a weekly basis [29]. It is a key determinant of the health outcomes associated with physical activity. Different frequencies are suited to different population groups and health goals, making an understanding of frequency essential for the advancement of sport science, public health, and exercise intervention strategies. Based on weekly occurrence, physical activity can be categorised into three types: Sporadic Physical Activity (Sporadic PA), Regular Physical Activity (Regular PA), and High-Frequency Physical Activity (High-Frequency PA).

Duration. The duration of physical activity refers to the length of time an individual engages in a single bout of activity, typically measured in minutes or hours [30]. Alongside intensity and frequency, duration is a core component that significantly influences the health outcomes of physical activity. Short duration activities help to reduce sedentary behaviour, moderate duration activities are in line with health guidelines, and long duration activities are suitable for high intensity training or fitness enhancement. Understanding the different frequencies of physical activity can help to develop health interventions for different groups and exercise goals [29].

1.2.3 Physical activity and health promotion

Physical activity is widely recognised as a cornerstone of health promotion and public health. A large body of evidence demonstrates its positive effects across multiple dimensions, including physical, mental, and social health [31]. It plays a critical role in the prevention and management of non-communicable diseases, such as cardiovascular disease, obesity, and type 2 diabetes, as well as in enhancing mental wellbeing and fostering social cohesion. In response, the World Health Organization has issued physical activity guidelines tailored to different demographic groups—children and adolescents (aged 5–17), adults (aged 18–64), older adults (65+), pregnant and postnatal women, individuals with chronic diseases, and people with disabilities—emphasising regular physical activity as a key strategy to enhance population health [28].

Physical health benefits. Physical activity significantly contributes to the prevention and management of chronic conditions across age groups and special populations [28]. For adolescents, regular engagement in physical activity improves cardiorespiratory fitness, supports healthy growth and muscle development, and mitigates the health risks associated with sedentary lifestyles [19]. Among adults, moderate-to-vigorous physical activity (MVPA) enhances muscular strength, regulates blood glucose, and improves metabolic function. Even sub-guideline levels of activity have been associated with a reduced risk of obesity, cardiovascular disease, and premature mortality. For older adults, MVPA not only supports cardiovascular and metabolic health but also strengthens the musculoskeletal system, lowering the risks of osteoporosis and sarcopenia [32]. In special populations such as pregnant or

postpartum women, physical activity is associated to a reduced risk of preterm birth, better postnatal recovery, and healthier weight management. For individuals with chronic diseases—such as type 2 diabetes, hypertension, coronary heart disease, and cancer—physical activity contributes to improved clinical outcomes and reduced mortality [33]. Similarly, for people with disabilities, including those with stroke, Parkinson's disease, spinal cord injuries, or multiple sclerosis, appropriately tailored physical activity offers measurable health and functional benefits.

Mental health benefits. In addition to its physical health impacts, physical activity is a powerful non-pharmacological intervention for improving mental health [34]. The mental health benefits vary across populations but remain consistently positive. Among children and adolescents, physical activity is associated with stress reduction, enhanced self-esteem, improved social skills, and cognitive development, including improved memory and academic performance [35]. For adults, regular physical activity alleviates work-related stress and anxiety, improves sleep quality, and enhances emotional regulation and resilience. In older adults, it plays a role in combating loneliness, fostering social interaction, and preventing cognitive decline [36]. For special populations—including individuals with mental health disorders, chronic illnesses, or physical impairments—physical activity serves as an effective complementary therapy, improving psychological wellbeing and functional independence.

Community and social health benefits. Beyond individual benefits, physical activity also contributes to community and social health [37]. Participation in physical activity enhances social cohesion by encouraging group engagement, inclusive interactions, and shared public space use. This, in turn, supports the development of healthier, more connected, and more equitable communities. Parks, green spaces, and other shared environments play a crucial role in facilitating these interactions and serve as platforms for promoting collective health [38].

1.2.4 Summary

Physical activity plays a vital role in promoting both individual and societal health. Nevertheless, a substantial proportion of the population continues to fall short of the physical activity levels recommended by global health guidelines. This highlights the urgent need for effective strategies to enhance public motivation and participation in physical activity [28].

Among the various environmental settings, parks represent one of the most accessible and frequently utilised spaces for engaging in physical activity [22]. Especially in high density urban settings, provide the most convenient place for the public to do exercise. As such, parks serve as critical venues for supporting daily movement and active lifestyles across diverse population groups [5]. Future research should therefore prioritise understanding how specific attributes of park environments influence physical activity behaviours. Emphasis should be placed on exploring how urban planning and design can strengthen the health-promoting

functions of parks. Ultimately, this knowledge will contribute to fostering healthier and more active populations.

1.3 Audit tool

1.3.1 Definitions of audit tool

Audit tools are one of the methodologies for the systematic assessment of environmental characteristics and are widely used in urban design and environmental management to measure and document physical environment features [39]. Audit tools offer objective measurements of the presence, function, availability, and condition of physical environment features using standardised criteria [40]. This empirical information and data provide policy makers and administrators with evidence-based to support policy making.

In park environment studies, audit tools are employed to assess attributes such as park surroundings and accessibility (e.g., signage, crosswalks, public transport, and parking lots), park activity areas (e.g., a variety of sport courts, playgrounds, and fitness areas), facilities and amenities (running tracks, benches for resting, picnic tables, and toilets), aesthetics (floral greenery, landscaping, fountains, and art exhibits), and safety (lighting, surveillance equipment, and emergency services) [39]. These assessments help to identify features that promote physical activity and can guide the (re)design of parks to better support active lifestyles. Thus, developing scientifically robust and reliable audit tools is crucial for optimising park design and enhancing public health outcomes.

1.3.2 Categories of environment assessment methodologies

Scientifically assessment of the environment is an essential topic in the urban environment studies. In addition to audit tools, there are various methodologies for the assessment of the urban physical environment. These methods fall into two main types: objective (e.g., environmental audit tools and geographic information systems) and subjective assessments (e.g., questionnaire surveys and interviews and focus groups) [4]. Each method offers unique strengths and limitations [41]. A clear categorisation of environmental assessment approaches allows researchers to select the most appropriate methods based on specific study objectives, thereby enhancing the rigour, relevance, and scientific contribution of the research.

Objective assessment methods. Objective methods involve standardised and reproducible measurements designed to minimise subjective bias and ensure data accuracy. Common objective approaches include audit tools and geographic information systems (GIS).

- Audit tool: conducted by trained researchers or observers, these tools systematically evaluate on-site or remotely observed environmental features. They provide direct,

empirical data to inform environmental modifications and policy development [42].

- Geographic information systems: it uses spatial data to measure large-scale environmental characteristics such as green space coverage, walkability, and connectivity. It can also be integrated with health and socio-demographic data for advanced spatial analyses that support urban planning and public health interventions [43].

Subjective assessment methods. rely on individual perceptions and experiences of the environment. Though potentially influenced by personal biases, these methods offer valuable insights into user needs and behavioural responses [44]. They include questionnaires (a widely used method for collecting self-reported data from residents regarding their perceptions of environmental attributes) and interviews and focus groups (qualitative approaches allow researchers to explore residents' experiences, preferences, and suggestions in depth. They are often used to supplement quantitative findings and provide richer contextual understanding) [45].

1.3.3 Strengths of the audit tool

Audit tools are extremely useful in providing quantitative data on the physical environment, particularly in assessing the urban environment and its contribution to physical activity. Compared to other objective and subjective assessment methodologies, audit tools offer several distinctive advantages.

Audit tools, as an objective assessment approach, allow for the systematic collection of quantitative data on smaller-scale physical environments; for example, by measuring park attributes such as the facility quality, path lengths, and the number of playing fields, to assess which attributes are most effective in promoting physical activity [46]. Unlike geographic information systems, which require advanced technical knowledge and are better suited for macro-level analysis [43]. Compared to subjective assessments, audit tools can provide more objective data support, reduce individual cognitive bias and reduce data bias, and provide objective evidence for researchers and those responsible for physical environment renewal [47].

In recent years, remote or virtual audits—conducted through publicly accessible satellite imagery and street view platforms—have gained popularity [42]. These methods significantly reduce logistical demands such as time and cost, especially when auditing large or widely distributed areas. These methods significantly reduce the consumption of logistical resources, such as commuting time and costs for on-site audits, especially when auditing large or widely distributed areas [48]. Remote audits expand the scale and efficiency of environmental assessments, offering new opportunities to develop scalable, scientific models for evaluating the built environment.

1.3.4 Summary

As an objectively standardised measure, audit tool enables the systematic assessment of the urban physical environment, such as parks, streets and neighbourhood environments[49]. By identifying environmental facilitators and barriers to physical activity, audit tools offer objectively data to support the design and implementation of healthier urban spaces [50]. Future research should continue to focus on the development, validation, and refinement of audit tool. Additionally, there would also be a need to emphasise the applicability of the audit tool in different cultures, socio-economic environments and urban density contexts to increase the value of its wider application in global urban studies.

1.4 Research background

Physical inactivity is defined as “less than or not in line with the World Health Organization's recommendation of at least 150 minutes of moderate physical activity or 75 minutes of vigorous physical activity or a combination of both intensities per week” [51]. Sedentary behaviour is “any waking behaviour characterized by an energy expenditure ≤1.5 metabolic equivalents (METs), while in a sitting, reclining or lying posture” [51]. The high-level epidemic of physical inactivity and sedentary behaviour is a crucial public health concern throughout the world [51]. They represent risk triggers for most non-communicable diseases, such as type 2 diabetes, obesity and overweight, cardiovascular disease, cancer and other adverse health outcomes [17]. These diseases are the major cause of death worldwide, accounting for 74% of all deaths [52]. Therefore, developing effective policies and interventions that promote physical activity and decrease sedentary behaviour to reduce the risk of chronic diseases has become public health priorities [53, 54].

It is known that a several factors, such as personal, family, social and built environment can influence physical activity [55]. Increasing evidence shows that the built environment is recognized as an important determinant in the promotion of physical activity and prevention of non-communicable diseases [56, 57]. Multiple systematic reviews provide evidence of associations between the built environment and health outcomes [22, 58]. Among built environment factors, public open space, such as parks and playgrounds, play an important role in promoting different health behaviours and outcomes. In relation to physical activity, these spaces serve both as venues for exercise and as destinations that encourage walking within neighbourhoods [4]. Parks, as unique settings in the built environment, can support residents to engage in active living while being relatively easy to modify and valued by residents [25, 59]. However, several studies show that certain park attributes may support or promote residents' physical activity. Therefore, understanding how parks attributes contribute to physical activity is important for public health efforts. To this end, assessing park attributes is an important step in supporting residents' physical activity to promote positive behaviours.

Previous studies have employed two main approaches: perceived and objective methods for evaluating park attributes and the relationship between these attributes and physical activity. Perceived measures typically involve questionnaires or interviews, asking residents about their

perceptions of park suitability for physical activity. In contrast, audit tools are a key objective method used by researchers to directly assess park environments. Several audit tools have been developed to measure the park's attributes concerning park use and park-related physical activity. Existing audit tools specifically developed for researchers include the Irvine-Minnesota Inventory to Measure Built Environments [60], the Bedimo-Rung Assessment Tool-Direct Observation [61], and the Environmental Assessment of Public Recreation Spaces Tool [62]. Other direct observation audit tools include the Public Open Space Tool [1], the Path Environment Audit Tool [63], and the Community Park Audit Tool [64]. Audit tools are useful for providing quantifiable data on the physical attributes of parks. However, these tools, among many others, have been developed and validated primarily in low-density urban areas in western countries (e.g., Canada, the United States, and Australia). The effectiveness and limitations of these tools in different urban contexts remain an important area of study.

1.5 Research questions

Urbanization has been rapidly growing in Asia resulting in populated dense urban areas [65, 66]. For instance, the urban population of Japan was approximately 116,522 in 2018, accounting for 91.6 % of the overall population [67]. Moreover, open space per capita in Hong Kong, with an extremely high population density (about 57,250 people per square kilometre), is far below the 9 square metres standard recommended by the World Health Organization [68]. The high population density, the lack of empty spaces and spatial fragmentation are key barriers to allocating new parks in dense urban areas [69]. The lack of physical activity space per capita tends to reduce the level of physical activity among residents. Thus, in such highly dense areas, it is practical to prioritise (re)designing existing parks to promote park-related physical activity and maximise their impact [24]. Furthermore, uniform evidence of the relationship between park attributes and physical activity differing between high- and low-density urban areas is still absent. For example, exploring the relationship between perceived attributes and physical activity in high-density areas by using tools developed in low-density areas tends to yield mixed results [70, 71].

To our knowledge, there appears to be just one park audit tool designed particularly for South Korea, with a population density of no less than 8,000 individuals per square kilometre [50]. However, audit items identified through the literature review only measure park attributes that influence physical activity in elderly individuals. In certain cases, the park audit areas were concentrated on areas where the elderly were active rather than the whole park. This approach may fail to consider other demographic groups and other areas of the park that support physical activity. The applicability, validity, and limitations of these existing tools in dense urban contexts for the whole population remains a limiting research gap.

1.6 Research objectives

Therefore, this study aims to develop a dense urban park audit tool to measure park

attributes that support physical activity in dense urban areas, which will help to explore the relationship between park attributes and physical activity and then inform the renovation of existing parks in dense urban areas to support better and encourage resident's active life. Additionally, to further save logistical resources consumed by on-site audits, this study aims to adapt audit tool to develop a remote audit version to virtual audit of park attributes that support physical activity in dense urban areas.

1.7 Thesis structure

The aim of this thesis is to develop and validate a comprehensive audit tool for dense urban areas, allowing the assessment of park environments that support physical activity. The study unfolds through several key stages, each of which is systematically presented in the appropriate chapter, as shown in Figure 1.3.

Chapter 1 introduces the context and the significance and purpose of this thesis. The role of parks in promoting physical activity and health and well-being is emphasised, as well as the important role of the audit tool as an objective assessment tool to provide objective data to support the renewal and design of parks.

Chapter 2 systematically reviews existing direct observation audit tools and identifies three major research gaps in the adaptability to urban context, the applicability to culture and the user-friendliness of their existing audit tools. A scientific basis is provided for the development of a new audit tool.

Chapter 3 details the development process of dense urban park audit tool, including the construction of the assessment framework, the importance assessment of the assessment framework, the quantitative assessment criteria, the pilot testing phase, and the modification and finalisation of dense urban park audit tool.

Chapter 4 reports on the validation of the reliability and validity of the dense urban park audit tool. It covers the selection of the study case, auditor training, on-site auditing and data collection, and statistical analyses of reliability and validity. The results show that audit tool demonstrates good reliability and validity as an environmental assessment tool for parks in dense urban areas.

Chapter 5 describes the process of adapting dense urban park audit tool to the remote audit version, using Google Earth Pro for virtual assessment. The chapter covers item adaptation, auditor training, data collection methods, and statistical analyses used to assess reliability and validity. The results indicate that remote audit version is both a reliable and valid tool for remotely assessing park environmental attributes that support physical activity.

Chapter 6 reviews the overall thesis framework, highlights the research strengths of this thesis, and discusses the research limitations.

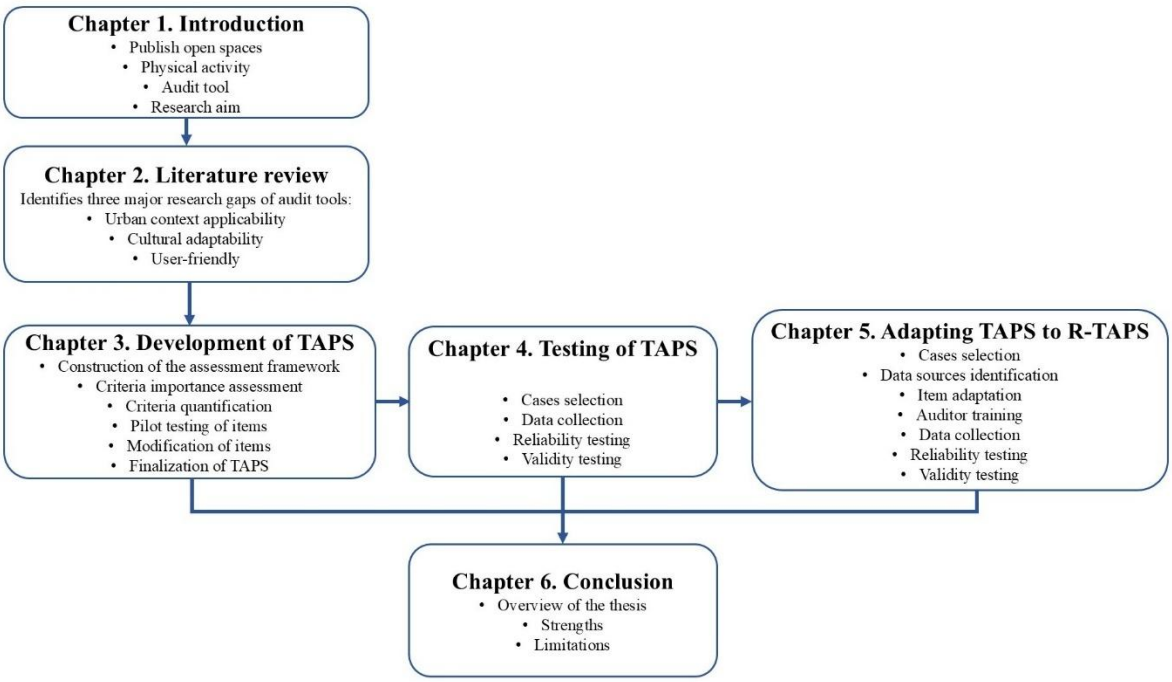

Figure 1.3. Structure of the thesis

Chapter 2 Literature review

2.1 Introduction

In the context of non-communicable diseases as the number one killer of mortality globally and rapid urbanisation in Asia [56], with extremely low rates of per capita occupancy of public open space that support physical activity, redesigning public open space, especially parks, in dense Asian cities to support the physical activity of their residents has emerged as a central topic of interdisciplinary studies [17]. In recent years, with intensive research on the relationship between public open space and health, how to systematically and objectively assess the physical environment characteristics of these spaces has become a key prerequisite for understanding the effectiveness of public open space interventions and developing science-based planning strategies [12, 54]. Audit tools are widely used in the fields of urban design and environmental research by recording and assessing the environmental attributes of public open space, providing strong data support for quantitative studies of the physical environment and their subsequent updating in the field [72].

This chapter aims to systematically review the literature to identify and analyse existing audit tools for assessing the environmental characteristics of public open space. The chapter summarises the core elements of audit tools such as research objectives, content structure, scope of application, usage, measurement reliability and validity, and examine existing audit tools and identify gaps in their application to park attributes related to physical activity in high-density urban contexts. Through the review of existing audit tools, not only can systematically sort out the existing research basis, but also clarify the gaps of the current measurement indicators and assessment dimensions, identify the research limitations of the existing audit tools in high-density urban environments, and provide theoretical support and methodological references as well as innovative points for the development of the new dense urban park audit tool in this study.

To ensure the scientific and reproducibility of this systematic review, the review operates in strict compliance with the process guidance of PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) [73].

2.2 Methods

2.2.1 Retrieval strategies development

The review was carried out on 8 August 2024, following the Preferred Reporting PRISMA guidelines [73]. Five major databases—Scopus, PubMed, Web of Science, ScienceDirect, and SportDISCUS—were searched, with Google Scholar serving as an additional resource to ensure comprehensive coverage. The search strategy involved three groups of terms related to

public open spaces (e.g., public open spaces, park, and green spaces), audit tools (e.g., audit, assessment tool, and measurement tool), and active lifestyles (e.g., physical activity, sedentary behaviour, walking, jogging, and running). These keywords are combined with each other by Boolean logicians (such as AND and OR) to identify relevant research. Table 2.1 shows the details of search terms and syntax.

Table 2.1. The search terms and syntax

Sets / Combination	**Search terms**
1: Public open space	“public open space” OR “park” OR “green space” OR "plaza"
2: Audit tool	“audit” OR “assessment tool” OR “measurement tool”
3: Active life style	“physical activity” OR “sedentary behaviour” OR “sedentary behavior” OR “walking” OR “running” OR “jogging” OR “cycling” OR “exercise”
Search combination	1 AND 2 AND 3

2.2.2 Screening criteria setting

In the screening process, two reviewers (Y.L & J. Z) independently screened the initial searched studies according to title and abstract. Suitable studies were screened in full text and were considered eligible when they fulfilled the following criteria: a) peer-reviewed journal studies with English full text were included. Descriptive articles, reviews, methodological papers or conference papers and book chapters were excluded. b) studies with exposures focused on public open spaces (e.g., park and playground) were included. Those studies related to private, entrance-fee green spaces (e.g., private gardens and golf courses) were excluded. c) studies considering the development, adaptation or validation of tools for on-site auditing were included. Studies focusing on remote auditing tools were excluded. d) studies with outcomes focusing on active lifestyles (e.g., physical activity and running) were included. Studies focusing on other outcomes (e.g., mental health) were excluded. e) Studies published between 2000 and 2024 were included. As shown in Table 2.2.

Table 2.2. Criteria for eligible articles.

a	Research papers of peer-reviewed journal with English full text were included. Descriptive articles, reviews, methodological papers or conference papers and book chapters were excluded.

b	Studies with exposures focused on public open spaces (e.g., park and playground) were included. Those studies that related to private, entrance-fee green spaces (e.g., private gardens, golf courses) were excluded.
c	Studies considering the development, adaptation or validation of tools for on-site auditing were included. Studies focusing on remote auditing tools were excluded.
d	Studies with outcomes focusing on active lifestyles (e.g., physical activity and running) were included. Studies focusing on other outcomes (e.g., mental health) were excluded.
e	Studies published between 2000 and 2024 were included.

2.2.3 Screening process

The screening of articles follows the PRISMA process, which consists of four stages: the initial identification stage, the screening stage, the eligibility assessment stage, and the inclusion stage [73].

The initial identification yielded 328 studies, including 321 obtained from the database and an additional 7 identified from Google Scholar. After duplicate screening, 125 articles were removed as duplicates, resulting in 203 unique articles. Two reviewers (Y. L & J. Z) screened the titles and abstracts of these articles independently in the eligibility assessment stage. After excluding 112 irrelevant articles, finally narrowed down the studies to 91 for full-text review. Ultimately, 22 studies fulfilled all the criteria and were included in the final review. From these eligible studies, 22 audit tools were identified.

Consistency in the review process between the two reviewers was over 97%. Any controversy or uncertainty about the studies reviewed was discussed with the third reviewer until a consensus was reached. A PRISMA flowchart was used to visualise the entire review process, including the search and screening stages, as shown in Figure 2.1.

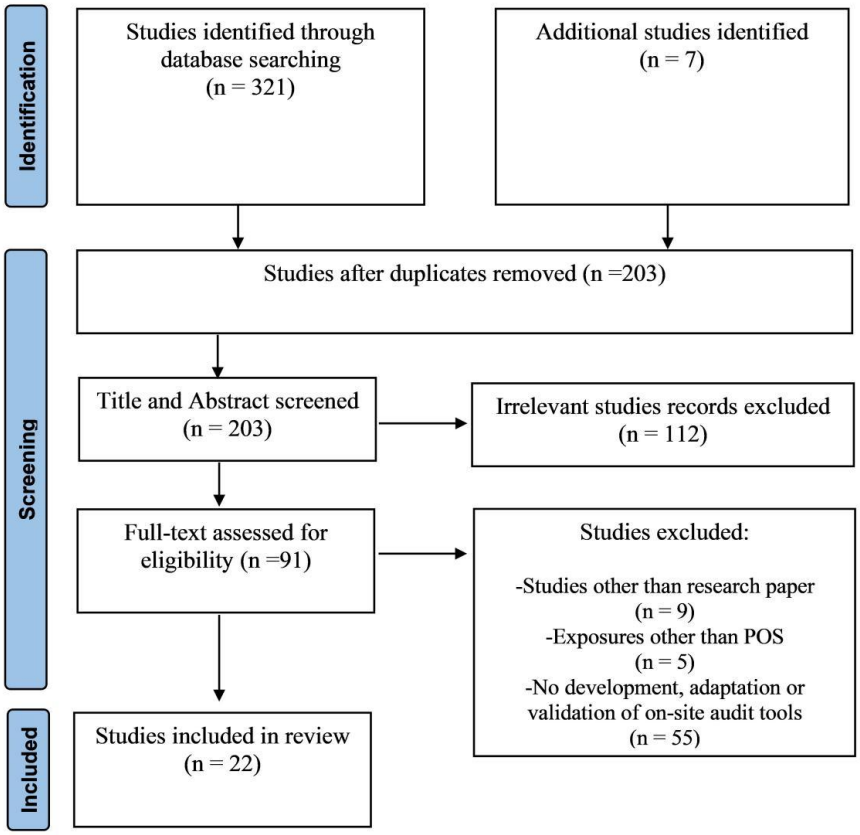

Figure 2.1. Flow diagram of the selection process of studies

2.2.4 Data extraction and collection

After completing the screening of the literature, systematic data extraction and collation of the audit tools mentioned in the studies that meet the requirements needs to be carried out. The process aims to standardise the comparative dimensions of audit tool information. By identifying the characteristics and differences among tools in terms of basic information, the design of tool development, tool validation, application and scope of application, it provides basic information and theoretical support for subsequent comparative analyses and new tool development.

Data extraction was recorded using a structured table, and all variables were generalised and expanded based on commonly used indicators for evaluating auditing tools in previous papers, which mainly include tool names, abbreviations, authors' name, the year of publication, geographic context in which audit tools were developed, the intended users of audit tools, the name of dimensions, and the number of items. The 22 eligible audit tools were extracted with this information and shown in Table 2.3.

Table 2.3. Summary of the direct observational audit tools

No.	Audit tool (abbreviation)	Author(s) (year)	Study location	Intended users	Items (n)	Dimensions
1	Recreation facilities assessment tool (-)	Cavnar, Kirtland [74]	-, USA	Administrators	61	1. Conditions 2. Safety 3. Maintenance
2	Public open space tool (POST)	Giles-Corti, Broomhall [1]	Perth, Australia	Experts	35	1. Activities 2. Environmental qualities 3. Amenities 4. Safety
3	Bedimo-Rung assessment tools with direct observation (BRAT-DO)	Bedimo-Rung, Gustat [61]	New Orleans, USA	Experts	181	1. Features 2. Conditions 3. Access 4. Aesthetics 5. Safety
4	Environmental assessment of public recreation spaces (EARPS)	Saelens, Frank [62]	Ohio, USA	Experts	646	1. Trails/paths 2. Specific use areas 3. Water-related areas 4. Amenities and facilities 5. Playground equipment and sport courts
5	Physical activity resource assessment instrument (PARA)	Lee, Booth [75]	Kansas, USA	N/A	34	1. Physical activity features 2. Amenities 3. Incivilities
6	Path environment audit tool (PEAT)	Philip J. Troped [63]	Massachusetts, USA	Experts and practitioners	36	1. Designs 2. Amenities 3. Aesthetics and maintenance of trails

7	System for observing play and recreation in communities (SOPARC)	McKenzie, Cohen [76]	Los Angeles, USA	Experts and park managers	7	1. Accessibility 2. Usability 3. Equipment availability 4. Supervision 5. Organisation
8	Children's public open space tool (C-POST)	Crawford, Timperio [77]	Melbourne, Australia	Experts	26	1. Recreational facilities 2. Availability of amenities 3. Number of playgrounds
9	New Zealand-public open space tool (NZ-POST)	Badland, Keam [78]	Waitakere, New Zealand	Experts	39	1. Activities 2. Environmental qualities 3. Amenities 4. Safety
10	Community park audit tool (CPAT)	Kaczynski, Wilhelm Stanis [64]	Kansas, USA	Experts and community members	140	1. Park information 2. Access and neighbourhood contexts 3. Park activity areas 4. Park qualities and safety
11	Neighbourhood green space tool (NGST)	Gidlow, Ellis [79]	Stoke-on-Trent, UK	Experts and community members	36	1. Accessibility 2. Recreational facilities 3. Amenities 4. Natural features 5. Incivilities 6. Overall usage
12	Recreational facility audit tool (RecFAT)	Ka Yiu, Macfarlane [47]	Hong Kong, China	Experts	111	1. Sports facilities' availability 2. Accessibility 3. Availability of supportive amenities 4. Condition of changing rooms 5. Condition of toilets

						6. Facilities' management 7. Policies 8. Environmental safety 9. Aesthetics 10. Social environments
13	Resilience for eating and physical activity despite inequality park audit tool (READI)	Veitch, Salmon [80]	Victoria, Australia	Experts	84	1. Accessibility 2. Lighting and safety 3. Aesthetics 4. Amenities 5. Pathways 6. Outdoor courts and sports ovals 7. Informal play spaces 8. Playgrounds
14	Parks, activity and recreation among kids tool (PARK)	Bird, Datta [72]	Montreal, Canada	Experts	92	1. Activities 2. Environmental qualities 3. Services 4. Safety 5. Overall impressions
15	ParkIndex (-)	Kaczynski, Schipperijn [81]	Kansas, USA	Experts	51	1. Distance to the nearest parks 2. Number of parks 3. Amount of park spaces 4. Average park quality indices
16	A pen and paper audit tool adapted from previous audit tools (-)	Flowers, Timperio [23]	Melbourne, Australia	Experts	35	1. Access and neighbourhood contexts 2. Activity areas within the parks 3. Park qualities and safety
17	Play space audit tool	Gustat,	New Orleans,	Experts	48	1. Overall park qualities 2. General playground overviews

	(PSAT)	Anderson [46]	USA			3. Surface features 4. Path features 5. Play structures and equipment
18	An audit tool adapted from SOPARC and CPAT (GGAT)	Shuvo, Feng [82]	Sydney, Australia; Singapore City, Singapore; Dhaka, Bangladesh	Experts	44	1. Accessibility 2. Safety 3. Activity spaces 4. Amenities 5. Landscape qualities
19	Urban green space quality assessment tool (RECITAL)	Knobel, Dadvand [18]	Barcelona, Spain	Decision-makers and experts	90	1. Surrounding environments 2. Accessibility 3. Facilities 4. Amenities 5. Aesthetics and attractions 6. Incivilities 7. Safety 8. Potential usage 9. Land cover 10. Animal biodiversity 11. Bird biodiversity
20	Senior park environment assessment in Korea (SPEAK)	Lee [50]	Seongnam and Daegu, Korea	Local government staff and community members	36	1. Accessibility 2. Amenities 3. Safety 4. Aesthetics 5. Recreation environments

21	Mexican public open spaces tool (MexPOS)	Medina, Hernández [83]	Mexico City, Mexico	Administrators, city planners, and policymakers	181	1. Food and wellness environments 2. Maintenance 3. Amenities 4. Legibility/signalling 5. Security 6. Perceived environments 7. Urban environments
22	KomBus audit toolbox (-)	Müller, Domokos [49]	-, Germany	Researchers and community members	495	1. Land use and destinations 2. Traffic safety 3. Pedestrian infrastructures 4. Cycling infrastructures 5. Attractiveness 6. Social environments 7. Subjective assessments 8. Children and adolescents 9. Seniors and persons with impaired mobility 10. Parks and public open spaces 11. Playgrounds

2.3 Results of literature review

This subsection provides a detailed introduction to the 22 environmental audit tools included in the review. It compares and analyses similarities and differences across tools in terms of development year, measurement dimensions, and number of items, with a particular focus on their application contexts, intended users, and their strengths and limitations in supporting physical activity. Based on this systematic review, several research gaps that have not been adequately covered were also revealed. These insights would provide an essential reference base for the development of dense urban park audit tool in this study.

2.3.1 Details of audit tools

The Recreation Facilities Assessment Tool. It is an environmental characterisation audit tool developed in the USA, to assess the overall quality and safety of community recreation facilities [74]. The tool is used by administrators and consists of 61 items focusing on three core dimensions: conditions, safety and maintenance. Based on structured observations, the tool provides a standardised assessment framework to help identify the quality of facilities that impact on user experience and participation in physical activity. The tool is easy to use and can be used by communities to update and maintain infrastructure facilities for physical activity. However, it has more limited indicators in terms of user accessibility and aesthetics. Nevertheless, the tool provides an important reference and practical basis for the design and development of subsequent audit tools.

The Public Open Space Tool (POST). It is an audit tool for assessing the environmental characteristics of public open space developed. in Perth, Australia [1]. POST is intended for use by experts and consists of 35 items covering four key dimensions: activity type, environmental quality, amenities and safety. POST emphasises the environmental characteristics of public open space that can support physical activity, focusing on the type of facilities relevant to the activity taking place, the aesthetics of the space, and safety, giving it a significant advantage in understanding how the public open space can support healthy lifestyles.

Bedimo-Rung Assessment Tool with Direct Observation (BRAT-DO). It is an environmental audit tool developed by Bedimo-Rung et al. to assess the relationship between the environmental characteristics of parks and the physical activity of their inhabitants through direct observation [61]. BRAT-DO consists of a conceptual model of five dimensions: functional features, facility condition, accessibility, aesthetic features and safety, and includes a total of 181 assessment items. BRAT-DO was developed to provide researchers with a systematic and standardised tool to objectively measure the extent to which the park environment supports physical activity. However, the complexity of BRAT-DO and the number of items may limit its application in resource-limited or non-specialist contexts. Therefore, future research could consider simplifying the structure of the tool while maintaining the comprehensiveness of the assessment to improve its usefulness and generalisability.

Environmental Assessment of Public Recreation Spaces (EARPS). EARPS is designed to systematically assess a wide range of physical environment features associated with physical activity in public recreation spaces [62]. Originally developed in Ohio, USA, EARPS is designed for professional researchers and auditors and includes a total of 646 items, making it the largest audit tool in terms of the number of items. The breadth and detail of EARPS provides detailed environmental data for research. However, this has also meant significant time, labour and training costs, limiting its wider application to assessments. Future tool development could draw on the structural strengths of EARPS while seeking possible paths to streamlining and intelligence to improve its application.

Physical Activity Resource Assessment Instrument (PARA) is designed to systematically assess the quality of resources available for physical activity in community settings [75]. The instrument consists of 34 items grouped into three core dimensions: 1) physical activity features (e.g., fitness equipment and ball fields), 2) amenities (e.g., benches), and 3) incivilities (e.g., broken equipment and graffiti). A key feature of the PARA tool is its simplicity and practicality, which allows the assessor to complete the observation of the site in a short period of time and to quickly determine the level of support and potential challenges of the resource environment through a standardised scoring system. It is particularly suitable for use in preliminary investigations, intervention assessments or in combination with other methods, such as questionnaires and GIS, to gain a comprehensive understanding of the influence of the environment on physical activity.

Path Environment Audit Tool (PEAT) is designed to assess the extent to which the trail and path environment supports physical activity, particularly walking and cycling [63]. Unlike others audit tool, the PEAT focuses on trail and is particularly suited to assessing the environmental quality of linear public spaces such as urban greenways and community walking routes. PEAT helps to identify and improve barriers to walking environments and provides policy makers and urban planners with an important evidence base on pedestrian friendliness to promote healthier urban mobility.

System for Observing Play and Recreation in Communities (SOPARC). It is a systematic observation tool developed in Los Angeles, USA, to assess participation in physical activity in public open space [76]. The most distinctive feature of SOPARC is the application of behavioural observation methods. Unlike traditional auditing tools that focus on environmental characteristics, SOPARC focuses on field observations of people's use behaviour and is particularly suited to analysing the use of parks, playgrounds and other open spaces. Observers record the number of users, gender, age group and intensity of physical activity (e.g., sitting, LPA, MPA and VPA) at specific times and locations to quantify the frequency and type of PA occurring in public open space.

Children's Public Open Space Tool (C-POST) is an audit tool designed specifically for public open space used by children [77]. It is used to assess whether children are provided with adequate, safe and attractive outdoor environments in urban spaces, with a particular focus on the configuration and distribution of play equipment. C-POST emphasises the match between

children's developmental needs and urban public open space and can be valuable in the development of child-friendly urban planning policies.

New Zealand-Public Open Space Tool (NZ-POST). It is an environmental audit tool developed in the New Zealand context, primarily for use by specialists, consisting of 39 items and four dimensions including: activities, environmental qualities, amenities and safety [78]. NZ-POST was developed to fill a gap in the systematic assessment of public open space quality in New Zealand urban design, with a particular emphasis on the supportive role of public open space in promoting physical activity and social interaction among residents. However, its city-specific focus may lead to its application and replication in other contexts.

Community Park Audit Tool (CPAT) is a community park audit tool developed in Kansas, USA [64]. CPAT encourages public and stakeholder participation in audits by providing simple and intuitive forms. It can be used by both experts and community members. It contains 140 items and four dimensions. CPAT provides an effective assessment tool at the community level and facilitates the identification of critical environmental factors affecting the utilisation of community parks, thus providing objective data to support environmental optimisation and public health interventions in community parks.

Neighbourhood Green Space Tool (NGST) is an audit tool developed in 2012 in Stoke-on-Trent, UK to assess neighbourhood green spaces [79]. Like the CPAT, the NGST is a tool that encourages both experts and community members to use it together. In addition, the NGST explicitly focuses on natural features as separate dimensions, including ecological elements such as trees and water bodies in the neighbourhood, emphasising the importance of a green and healthy environment as well as biodiversity. NGST consists of a total of 36 items divided into six assessment dimensions, which are applicable to the assessment and improvement of green spaces at the community scale.

Recreational Facility Audit Tool (RecFAT) is an audit tool developed in Hong Kong, China, and specifically designed to be used by experts to assess the environmental characteristics of recreational and sports facilities [47]. RecFAT focuses on the comprehensiveness and quality of the management of recreational facilities and sports activities in a dense urban context. It consists of 111 items and 10 dimensions, of which the “facility management” and “policy” dimensions are rare, indicating that RecFAT not only focuses on the physical environment, but also emphasises on institutional safeguards and service quality. RecFAT was born in Hong Kong, a highly urbanised and land resource-constrained environment, and provides a localised assessment tool framework for high-density urban areas in Asia, as well as an important reference for the subsequent development of regional tools.

Resilience for eating and physical activity despite inequality park audit tool (READI) is an audit tool for assessing community park environments to promote diet and physical activity among low socio-economic status groups [80]. READI was developed with the core objective of promoting health equity, with a special emphasis on resource-poor communities. In all, READI contains 84 items covering eight dimensions. It not only considers the availability and condition of facilities, but also looks at whether the environment is sustainable, safe, and

accessible. READI is particularly suitable for assessing the allocation of resources to health promotion in urban environments with large socio-economic disparities.

Parks, activity and recreation among kids tool (PARK). It is an audit tool that focuses specifically on which environmental characteristics promote children's active participation in the open spaces [72]. PARK was developed in 2015 in Montreal, Canada, specifically to assess park environments to promote children's physical activity. PARK is developed based on a child's perspective to assess the number and type of facilities for child-related activities, the aesthetics of the park, its safety and the availability of child-friendly design. A total of 92 items are included in PARK, covering five dimensions. It is used by professional evaluators and provides an objective basis for improving children's facilities in parks to enhance children's daily physical activity levels.

ParkIndex is an indicator tool developed by Kaczynski, Schipperijn [81]. to quantify the accessibility of park resources to residents. In contrast to the CPAT previously developed by Kaczynski, ParkIndex is centred on residential neighbourhoods and measures the accessibility of neighbourhoods to parks and the quality of parks. It consists of 51 items and four dimensions. It provides a geospatial indicator, ParkIndex, by combining 'quantity-quality-accessibility', which can be used to analyse inequalities in the distribution of park resources between different communities through a combination of data integration and GIS analysis.

A pen and paper audit tool is an adapted public open space assessment tool based on previous auditing tools (e.g. CPAT and POST) designed to assess the effects of park environments on physical activity through a simple pen-and-paper approach [23]. A pen and paper audit tool was developed in Melbourne, Australia to assess three dimensions: accessibility and neighbourhood environment, including the number of entrances to parks, and connectivity to public transport; activity areas within parks, including sports fields and children's play areas; and park quality and safety, including lighting, and safety features. It is designed to be simple and easy for non-specialists to record and assess quickly in the field and is suitable for preliminary investigations of park environmental assessment projects. However, pen-and-paper recording may have limitations in data integration and long-term monitoring.

Play Space Audit Tool (PSAT) is a very simple audit tool for assessing the "playability" of children's play spaces [46]. It is based on children's play spaces in the urban context of New Orleans, USA, and includes four dimensions: playground profile; surfaces and topography; pathways; and play equipment and structures, emphasising the diversity, safety and maintenance of children's play spaces. PSAT can summarise playground conditions and characteristics, helping to compare different playgrounds. PSAT has the potential to assist communities in assessing their play spaces and identifying priorities for resource improvements.

An audit tool adapted from SOPARC and CPAT (GGAT). It is an audit tool that combines the dynamic observation method of SOPARC with the environmental character assessment method of CPAT [82]. It focuses on park user behaviours (e.g. activity intensity and type), as well as a detailed assessment of the park's environmental setting, facilities and landscape features, and is both a dynamic and static assessment. GGAT consists of five

dimensions: accessibility, safety, activity space, amenities and landscape quality, with a strong focus on the landscape quality dimension, to assess the importance of the quality of urban greenspaces for the promotion of recreation for older people. GGAT is one of the few audit tools that has been developed and validated in multiple countries (Australia, Singapore, Bangladesh), reflecting the cross-cultural applicability of its design.

Urban green space quality assessment tool (RECITAL) is a tool that contains a total of 90 items across 11 dimensions, including surroundings, accessibility, facilities, amenities, aesthetics and attractiveness, uncivilised behaviour, safety, potential use, ground cover, and biological diversity of animals and birds [18]. It was developed and validated in 149 urban green spaces in Barcelona, Spain in 2021 by Knobel et al. Unlike most audit tools that focus only on environmental characteristics in relation to human activities, RECITAL incorporates animal and bird diversity as independent dimensions, focusing on ecosystems and environmental sustainability, which makes it innovative and forward-looking in urban green space research.

Senior park environment assessment in Korea (SPEAK). It is a park environment assessment tool designed specifically for the elderly to promote physical activity based on the growing elderly population in the cities of South Korea [50]. SPEAK is a senior-friendly tool in the context of dense Asian cities, with a special focus on the older people's experiences and needs when using urban green spaces. It fills the gap of many current audit tools that ignore the friendliness of spaces for older people's activities in the context of dense cities, and can provide important data to support the construction of age-friendly public open space policies in dense cities.

Mexican Public Open Spaces Tool (MexPOS). It is a multidimensional audit tool for public open space developed for the Mexican urban context, with special emphasis on the integration of health promotion and urban governance in Mexican cities [83]. Unlike other audit tools, MexPOS covers the dimensions such as eating and healthy environments, visualisation systems, and the subjective perception of users, and includes a total of 181 items. It emphasises the multifunctionality of public open space in promoting health and social well-being.

KomBus audit toolbox is a comprehensive, multi-disciplinary and multi-population environmental assessment tool developed in Germany 2023 [49]. It is currently the most extensive and detailed tool with 495 items. It covers 11 dimensions and systematically integrates objective environmental factors such as land use, traffic safety, pedestrian and cycling infrastructure, and the needs of different groups (e.g. children, youth, elderly, and mobility-impaired people). This makes KomBus audit toolbox widely applicable to overall urban liveability and inclusiveness urban planning studies.

2.3.2 Development trends in audit tools

According to a summary and analysis of the trends in the development of the 22

environmental auditing tools reviewed in this article, the development of these tools spans the period from 2004 to 2023 (as shown in Figure 2.2). One of the first peaks in the number of audit tools occurred in 2006, such as BRAT-DO [61], EARPS [62], PEAT [63], and SOPARC [76], followed by a continuous growth after 2010. In recent years, auditing tools have evolved towards multidimensionality and comprehensiveness, especially after 2020, showing a trend towards cross-domain integration and technology extension, such as PSAT [46], RECITAL [18], GGAT [82], KomBus [49]. This evolution reflects a progressive change in studies from a focus on the infrastructural state of the environment to more complicated social, ecological and policy dimensions.

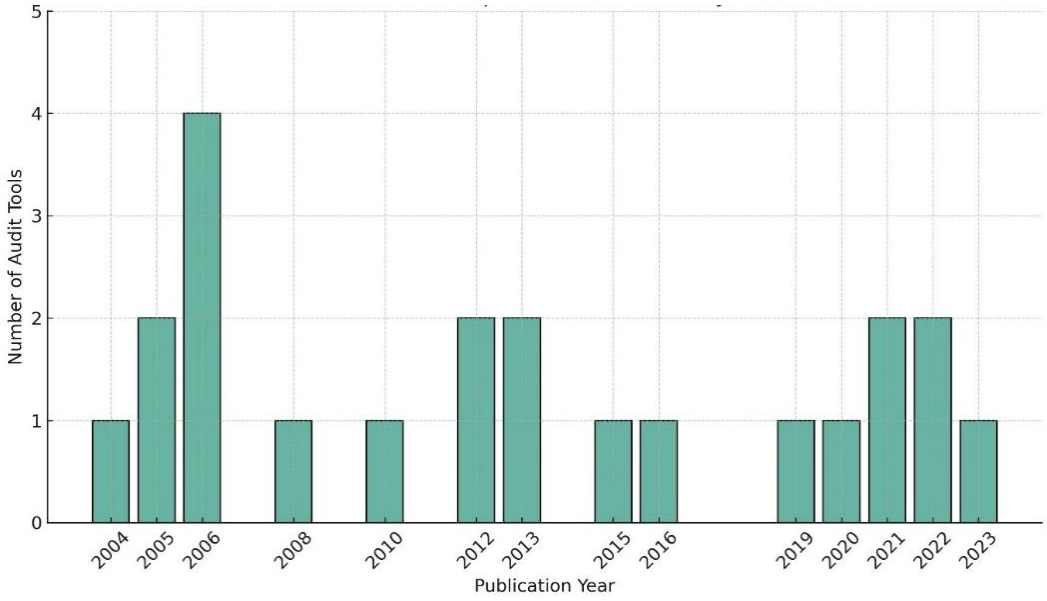

Figure 2.2. Trend in development of audit tools by year

2.3.3 Geographic distribution of audit tools

The development of the 22 auditing tools reviewed in this paper has been concentrated in Western countries (as shown in Figure 2.3). For example, EARPS [62], SOPARC [76], and CPAT [64] developed in the United States; POST [1], C-POST [77], and READI [80] in Australia; PARK in Canada [72]; as well as in European countries such as NGST in the United Kingdom [79], RECITAL in Spain [18], and KomBus in Germany [49]. Some of these tools were developed involving Asian cities, such as RecFAT developed in Hong Kong [47], SPEAK, which specifically targets the elderly population in South Korea [50], and GGAT, which involves Singapore and Bangladesh [82].

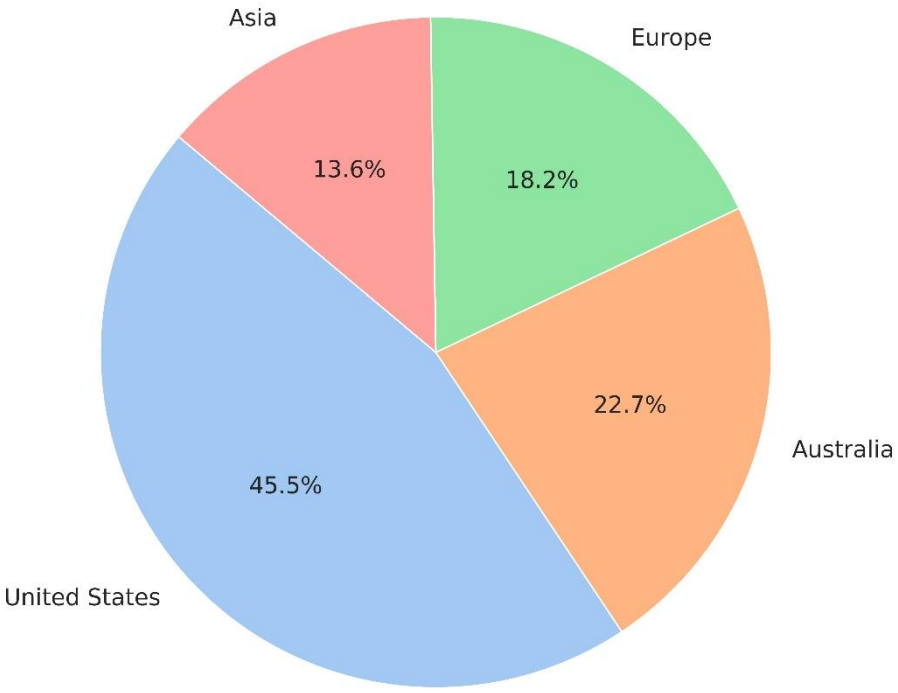

Figure 2.3. Geographic distribution of audit tools

2.3.4 Diversity of intended users

Based on the 22 audit tools reviewed, they were found to be mainly targeted at expert groups including researchers, urban planners, public health professionals, and so on, which accounted for 86 % of the tools. For example, EARPS [62], RecFAT [47], and BRAT-DO [61] are specifically designed for professional use. About 36 % of these audit tools allow community members to participate in their use, such as CPAT [64], NGST [79], SPEAK [50], and KomBus [49]. In addition, some of the tools are designed to operate for government administrators (e.g. MexPOS) [83], practitioners (e.g. PEAT) [63] and even cross-border decision makers (e.g. RECITAL) [18]. This indicates that there has been growing attention to multiple participants in the existing audit tools. Several audit tools have been developed specifically for different groups, for example, SPEAK, an environmental audit tool that specifically assesses physical activity affecting the elderly in South Korea [50], and C-POST [77] and PARK [72], which assess environmental factors in children's play areas.

2.3.5 Characteristics of audit items

Among the 22 audit tools, it was found that their number of audit items varied significantly, ranging from only 7 (SOPARC) [76] to as many as 646 (EARPS) [62] (as shown in Figure 2.4).

Of these, most of the audit tools contained around 30 to 100 items to cover multiple dimensions. The number of items is closely related to the level of complexity of using the audit tools, and also indicates the expertise of the target population for which they are intended to be used. For example, EARPS is designed to be used by specialists, with a total of 646 items to ensure that EARPS is specialised, comprehensive and all-encompassing [62]. In addition, RecFAT [47] and KomBus [49] have more than 100 items and emphasise exhaustive assessment, while SOPARC [76] and PEAT [63] have less items and simple structures, which are more conducive to quick on-site audits by auditors. Therefore, it is recommended that the balance between comprehensiveness and practicality in the development of future audit tools is particularly critical.

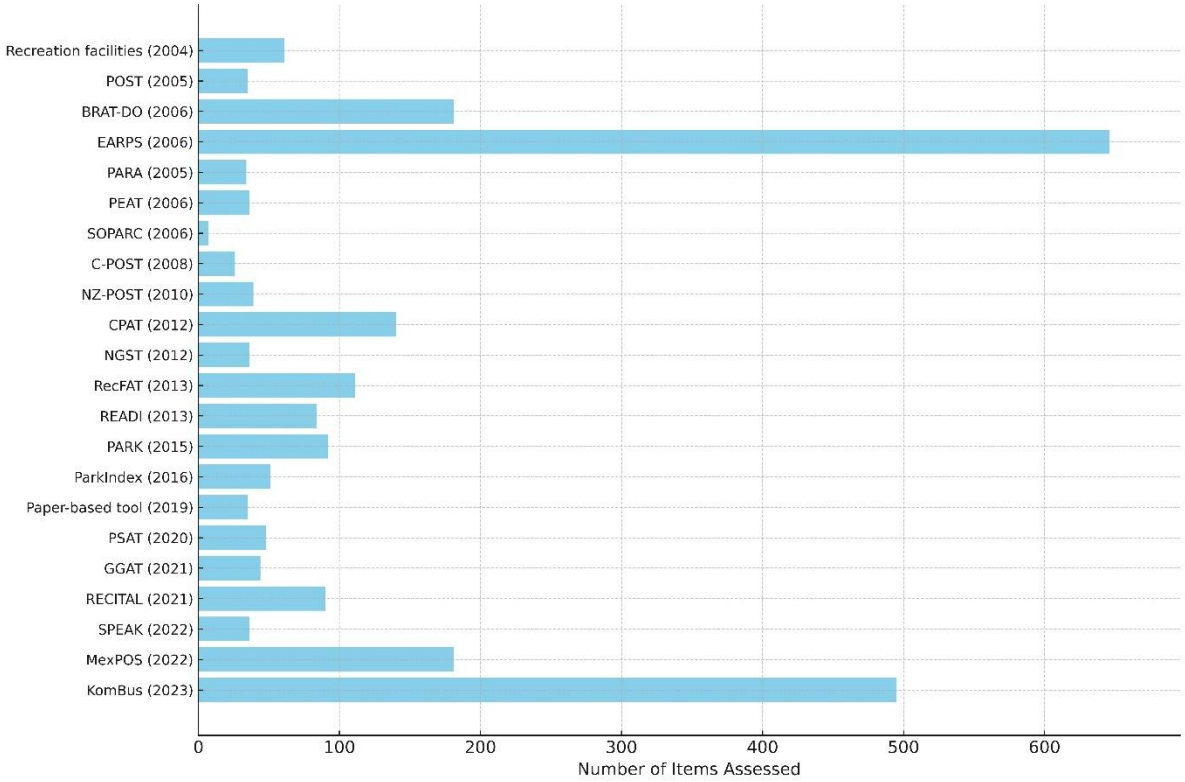

Figure 2.4. The number of audit items

2.3.6 Characteristics of dimensions

Table 2.4 shows the frequency of dimensions covered by audit tools. Among the 22 audit tools, the most frequently considered dimensions were amenities and accessibility, at 63.6% and 59.1% separately. The next dimensions in order of ranking are safety (54.5%) and aesthetics (40.9%). These four dimensions form the basic framework of the audit tools' assessment. Based on this framework, some of the audit tools expanded on rarer dimensions according to their project objectives. For example, in the case of ecology and biodiversity, RECITAL considered the dimension of ‘diversity of animals and birds’ to assess the ecological

functioning of the parks [18]; RECITAL [18] and KomBus [49] consider the 'social interactivity' and 'subjective assessment' dimensions in order to assess the impact of the social environment and the subjective experience of the user in physical activity. In addition, RecFAT includes dimensions related to facility management and policy support, and is an audit tool that considers the relationship between policy and institutional dimensions and physical activity, emphasising the important role of policy and institutional dimensions in affecting physical activity among residents [47]. This reflects a trend in the development of audit tools from focusing on the 'physical environment' to the 'integrated social environment'.

Table 2.4. The frequency of dimensions

Dimensions	**Frequence (N=22)**	**Percentage (%)**	**Tools covering the dimension**
Amenities	14	63.6%	POST, BRAT-DO, EARPS, PARA, PEAT, C-POST, NZ-POST, CPAT, NGST, RecFAT, READI, PSAT, RECITAL, SPEAK
Accessibility	13	59.1%	POST, BRAT-DO, SOPARC, NZ-POST, CPAT, NGST, RecFAT, READI, GGAT, RECITAL, SPEAK, PARKINDEX, C-POST
Safety	12	54.5%	BRAT-DO, POST, PARA, CPAT, NGST, RecFAT, READI, RECITAL, SPEAK, GGAT, C-POST, MexPOS
Aesthetics	9	40.9%	BRAT-DO, PEAT, RecFAT, READI, RECITAL, SPEAK, PARK, POST, NGST
Activities/Activity areas	8	36.4%	CPAT, READI, PARK, NZ-POST, C-POST, PEAT, EARPS, GGAT
Playgrounds	5	22.7%	C-POST, PSAT, READI, KomBus, EARPS
Social environment	3	13.6%	RecFAT, KomBus, RECITAL
Incivilities	3	13.6%	PARA, NGST, RECITAL
Biodiversity	2	9.1%	RECITAL, KomBus
Management/Policies	2	9.1%	RecFAT, MexPOS
Pathways/Trails	4	18.2%	EARPS, PEAT, PSAT, READI

Usage/Potential use	3	13.6%	RECITAL, NGST, SOPARC
Environmental quality	4	18.2%	PARK, POST, NZ-POST, KomBus
Urban environment context	3	13.6%	MexPOS, KomBus, CPAT

2.4 Discussion of research gaps

Based on a systematic review of 22 direct observation-type audit tools for assessing park environments to support physical activity, a comparative analysis was conducted. This subsection reveals gaps in the existing literature in three key areas: urban context applicability, cultural adaptability and user expertise. The following section will refine the research gaps in these three areas.

2.4.1 Inadequate applicability in dense urban contexts

Most previous audit tools development has focused on low-density urban contexts. The results of the systematic review showed that 82% of the audit tools were developed in low-density urban contexts, such as the central suburbs of the United States and coastal cities in Australia. These areas are typically characterised by having more public open space, lower building densities and more dispersed demographics [84]. These characteristics provide a natural advantage for the planning and allocation of park spaces that support physical activity. However, the spatial characteristics of dense urban areas are very different.

There is a lack of audit tools tailored to the specific context of dense urban areas. In dense urban areas, high population concentration, limited land availability and complex surrounding environments are typical challenges [58]. For example, in dense urban areas, parks are often surrounded by buildings, and this limited available land can constrain the size, facility allocation and function of the parks [69]. In addition, factors such as traffic jams and noise pollution caused by dense population and buildings have a direct impact on the safety, accessibility and comfort of parks. This would significantly reduce the role of parks in supporting physical activity for residents.

However, current audit tools rarely consider assessing parks in dense urban areas. Only very few of the tools reviewed have been developed in dense urban areas, such as SPEAK in Seoul, South Korea [50]. However, its coverage is narrow, targeting physical activity only for the elderly population in dense urban contexts in South Korea, potentially ignoring a wider range of populations and dense spaces in other contexts [50].

2.4.2 Insufficient adaptability to Asian cultures

Previous audit tools were mostly developed under Western societies. According to the review in this study, about 86% of the audit tools were developed in North America, Australia and Europe, reflecting the logic of use in Western urban parks, which is less adaptable to other cultures, such as Asia. Since social cultures and norms can influence the use of parks in physical activity [85], there is a need for culturally adapted audit tools. For example, in some cultural contexts, parks may be used more for group activities, taking on socially orientated functions such as group dances, community cultural exhibitions, and family gatherings [39]. This requires more open spaces and specific facilities, such as broad plazas, which may not be prioritised by other audit tools.

2.4.3 Limited diversity of intended users

Audit tool users are highly concentrated in professional groups. According to the findings of the review, 86% of the audit tools were designed for specialists, including researchers, urban planners, policymakers and public health professionals [63]. While these tools provide a detailed and comprehensive assessment of the urban environment through a highly technical and professional approach, they also limit their applicability to members of the general community non-professionals [64]. Currently, there is a lack of simplified tools for a wide range of populations. Including potential users of the audit tool to community members and other non-professional users would not only facilitate the dissemination of the audit tool but would also help to increase community participation and diversity of data sources in environmental assessment projects [64]. An environmental renewal strategy that reflects the needs of all users is a critical indicator of scientific intervention.

2.5 Summary

In summary, there are significant research gaps in the current audit tools regarding applicability to urban contexts (especially dense urban areas), cultural adaptability (especially Asian contexts), and user diversity (public friendliness). These gaps not only limit the dissemination and application of the audit tool in diverse urban environments but also limit the scientific assessment of the environment in diverse urban contexts.

To address these gaps, this study aims to develop and test a novel audit tool: dense urban park audit tool, for assessing park attributes that support park-related physical activity in dense urban environments in Asia. The characteristics of dense urban park audit tool consider 1) spatial characteristics and functional applicability for dense urban areas; 2) environmental dimensions and criteria for parks that support physical activity in the context of Asian cultures; and 3) the design and promotion of user-friendly auditing tool.

Chapter 3 Development of audit tool

3.1 Introduction

Based on the research gaps identified in the systematic literature review in the previous chapters:1) most audit tools were developed in low-density areas and failed to adequately adapt to the spatial characteristics of dense urban areas; 2) the vast majority of audit tools were developed and tested in Western contexts, ignoring the activity spaces and their characteristics required for residents' physical activity needs and preferences under other social norms and cultures; 3) the existing audit tools are based on the specialists with professional skills as the main target users, and the lack of a general user-friendly and easy-to-use audit tool limits the feasibility of the tool's dissemination and community engagement. Therefore, this study tries to fill these gaps by developing a novel audit tool: dense urban park audit tool, to assess the park attributes in dense Asian urban contexts and to provide objective data for park renewal to facilitate physical activity among residents. Dense urban park audit tool focuses on the applicable dense urban context; the adaptation of activity types and preferences under Asian social norms; and the diversity of user types and user-friendliness.

This chapter describes the process of design and development of dense urban park audit tool. It is developed to serve the need for optimising park environments in the context of dense urban areas in Asia and is oriented towards the promotion of physical activity. In line with this aim, the development of audit tool consisted of the following five steps:

a) Establishment of a preliminary assessment framework. A systematic review of 22 existing audit tools was conducted to identify dimensions and criteria relevant to the promotion of physical activity in parks. Based on this, an initial framework was constructed, comprising 5 dimensions and 31 environmental criteria that are most relevant to activity-friendly park environments.
b) Importance scoring. Experts from various fields—including public health, urban planning, sport science, and community development—were invited to assess the relative importance of each dimension and criterion. The Fuzzy Delphi Method was employed to synthesise expert consensus, ensuring the selected components were both scientifically grounded and contextually appropriate for dense urban environments.
c) Quantitative audit items. Based on the selected criteria, a series of audit items were generated to assess environmental features in terms of presence, usability, quantity, quality, condition, and maintenance. Depending on the nature of each item, a combination of objective binary scales (e.g., yes/no) and subjective ordinal scales (e.g., three-point ratings) were used. These items enable the quantification of environmental characteristics that influence park-based physical activity.
d) Pilot test. After the initial generation of audit tool, auditors conducted a pilot test of the preliminary version of audit tool in a variety of dense urban parks to examine the operability of audit tool items.

e) Revision of audit tool. Combining the data from the pilot test and the feedback from the auditors, the item descriptions, scoring criteria and the structure of the tool were repeatedly revised and optimised, resulting in a final version of the official audit tool with a clear structure, reasonable content and operability.

This chapter will systematically introduce the development and design process of audit tool, clearly demonstrating the whole process of audit tool from framework construction, framework assessment, item development and structure formation, and providing a strong foundation for subsequent on-site audits and validation.

3.2 Methods

3.2.1 Establishment of a preliminary assessment framework

Identifying key attributes of the park environment that support physical activity is the first step in developing an audit tool. Based on a review of prior relevant audit tools and literature, this study builds a preliminary framework for assessing park environmental attributes that influence residents' physical activity. Although previous research has identified several attributes of the built environment that facilitate residents' physical activity, they are limited to empirical cases in research and may not be applicable to dense urban areas. To address this challenge, this study extracted park environmental dimensions and criteria that are strongly associated with physical activity through a systematic review of the 22 park audit tools examined in Chapter 2 and accordingly built an initial assessment framework for supporting physical activity in dense urban areas (as shown in Table 3.1).

Table 3.1. Preliminary assessment framework

Dimensions	Criteria	Descriptions	References
Park surroundings and accessibility	Entrance points and sign	The number, size, distance and attractiveness of park entrances, as well as park signs such as park maps, opening hours, rules and prohibitions, affect whether people choose to enter the park.	[18, 75, 86-89]
	Traffic safety	The traffic control at the intersections around the park entrances, the presence of traffic lights and crosswalks, and safety affect whether people choose to pass through the intersections and enter the park.	[79, 90-92]
	Park boundary	The type (e.g., sidewalks, bicycle lanes), width,	[18, 75,

		surface material, maintenance management, supporting facilities, etc. of the boundary roads in the park will affect whether people can enter the park easily.	86, 89, 91]
	Public transport station	The presence of and distance to public transport station affect people's choice of visiting parks.	[90, 91]
	Parking lot	The presence, number, type (e.g., bicycle racks, private parking spaces), distance to, condition. of parking lots influence whether people to visit the park or not.	[75, 89, 90]
Activity areas	Sport court	A variety of courts in the park (e.g., basketball courts, soccer fields, baseball fields, tennis courts, volleyball court etc.) provide space for people to exercise.	[88, 89, 93, 94]
	Playground	An area that provides equipment such as swings, seesaws, slides, trampolines, carousels, rock climbing, etc., mostly used by children and teenagers.	[88, 94, 95]
	Running and cycling track	Refers to paths designed specifically for running or cycling, as distinct from regular paths in the park, even if someone is running on regular paths.	[18, 88, 89, 94]
	Fitness area	An area where a variety of exercise equipment is available for public use, whether indoors or outdoors.	[75, 88, 89, 92]
	Swimming pool	An area with specific types of leisure activities.	[75, 94, 96]
	Skateboard area	An area with specific types of leisure activities.	[18, 64, 79, 88]
	Skating rink	An area with specific types of leisure activities.	[97]
	Water sport	Water sports are based on the presence of water bodies (lakes or seas) in the park, such as rowing or kayaking, water skiing, swimming, surfing, etc.	[88, 96]
	Open/Green space	An open space can be provided for people to freely define their activities (e.g., kite flying, dog walking, chasing and playing, picnic, etc.).	[88, 89, 93]
Facilities and amenities	Path	Provide opportunities for walking for transportation or leisure walking.	[88, 89, 93]
	Public toilet	Provide necessary service facilities for park visitors.	[88, 89, 94]

	Shelter and pavilion	Shelters and pavilions in the park provide spaces for visitors to stay and rest temporarily. It also provides shelter during inclement weather such as hot sun, rain or snow.	[89, 93, 94]
	Drinking fountain	Provide convenient service facilities for people to carry out physical activities in the park.	[88, 93, 94]
	Vending machine	Provide convenient service facilities for people to carry out physical activities in the park.	[64, 89]
	Bench	Furniture that provides rest for activities in the park	[88, 93]
	Picnic table	Furniture that provides rest for activities in the park	[89, 93, 94]
	Trash can	Provide proper waste disposal for visitors.	[88, 89, 94]
Aesthetics	Water feature	The water features in the park attract visitors and provide opportunities for a variety of physical activities, such as walking or running around the lake, boating, fishing, etc.	[88, 93, 94]
	Vegetation and landscape	Design of vegetation and landscaping help to attract visitors visit the park.	[88, 93]
	Public art	The presence of public art (e.g., murals, sculptures, gallery) in the park more or less attract visitors to visit the park.	[18, 88, 93]
	Graffiti	The presence of graffiti makes people less interested in being in a particular space.	[88, 93]
	Litter	The presence of litter and poor management (e.g., stink) will be an obstacle to people's activities in a particular space.	[79, 88, 93]
Safety	Lighting	Sufficient lighting in the park provides visitors with a clear view and give a higher sense of safety.	[89, 90, 94]
	Surveillance equipment	Surveillance equipment (e.g., cameras) helps keep people safe in the park and acts as a deterrent to crime.	[18, 92]
	Emergency device	Emergency devices exists to provide visitors with emergency first aid in the event of an emergency.	[92, 96]
	Warning sign	Setting up warning signs (e.g., no swimming, electric shock, etc.) in potentially dangerous places in the park provide visitors with safety information.	[18, 79, 94]

The framework contains 31 environmental criteria categorised into five dimensions: park surroundings and accessibility [88, 98], activity areas in park [75], park facilities and amenities [40, 62], aesthetics [90, 99], and park safety [50, 100].

1) Park surroundings and accessibility. This dimension focuses on the neighbourhood environment surroundings the park and the accessibility of the park, including pavements, crosswalks, visibility of park entrance points, connectivity and safety of public transport, and parking management. Studies have indicated that residents prefer to use parks that are conveniently accessible and located on the living routes.

2) Activity areas. This dimension covers areas of the park which are specifically used for physical activities such as sports courts, playgrounds, fitness equipment, walking trails, etc. These areas are used by different age groups such as children, elderly and adults. Studies have shown that the type, quantity, and quality of activity areas are directly related to the way different populations engage in physical activity in parks.

3) Facilities and amenities. This dimension includes the provision of supportive facilities such as drinking fountains, toilets, benches, shelters, etc. within the park, and their quality and maintenance affect the continuity and comfort of park use. This dimension is emphasised in many park audit tools, and its effectiveness has been demonstrated in several studies.

4) Aesthetics. Aesthetic dimension is one of the perceived dimensions of park environments that support physical activity. Aesthetically pleasing and clean environments, such as greenery, landscaping, visual openness and cleanliness, are considered to contribute to people's psychological well-being and stimulate their willingness to stay and be active.

5). Safety. Safety dimension is a perceived dimension that includes lighting, policing facilities, and vandalism. It has been shown that lack of safety is a significant barrier to women and older adults using parks for activities.

This initial assessment framework comprises dimensions and their sub-criteria that have been repeatedly validated in several established auditing tools and show moderate to high validity in different contexts. This framework provides a theoretical foundation for follow-up importance assessment, criterion screening and consensus building by using the fuzzy Delphi method. Additionally, it provides a systematic structure for the quantification of subsequent measurement items and audit tool development.

3.2.2 Importance scoring

To ensure that the dense urban park audit tool criteria effectively support physical activity for residents in dense urban environments, an assessment of the importance of 31 environmental criteria was conducted. Fuzzy Delphi method was used to assess the importance of the 31 environmental criteria to support physical activity in dense urban areas to reach a consensus in the expert panel.

Fuzzy Delphi method. Dalkey and Helmer introduced the Delphi method in 1960 as a procedural approach to systematically present the opinions of a panel of experts[101]. Ishikawa, Amagasa [102] introduced the concept of fuzzy theory into the Delphi method, established two methods of cumulative number distribution maximum-minimum and fuzzy integral, and integrated the opinions of experts into a fuzzy number process, which resulted in fuzzy Delphi method. This method has been extensively applied in various studies, such as tourism management [103], regional governance [104], environmental renewal strategies [105] and design schemes [106].

Survey design. To assess the importance of the 31 criteria to support physical activity in dense urban areas, an importance questionnaire was created using an online surveys platform: SurveyMonkey (https://www.surveymonkey.com/). For the complete questionnaire, please see Appendix 1. The experts were informed that this questionnaire aimed to assess the importance of park environmental criteria in supporting residents' physical activity in the context of dense urban areas and were asked using the 5-point Likert scale to answer the importance of each criterion (as show in Figure 3.1). For example, "In the activity areas dimension, please assess the importance of the criterion ‘playground’ in supporting residents’ park-related physical activity in dense urban areas" and only one answer can be selected, such as very unimportant, unimportant, neutral, important, and very important (as show in Figure 3.2).

1	2	3	4	5
Very unimportant	Unimportant	Neutral	Important	Very important

Figure 3.1. Five-point Likert scale

(Please assess the importance of each criterion in supporting residents' park-based physical activity)

	Very unimportant	Unimportant	Neutral	Important	Very important
6. Sport court	○	○	○	○	○
7. Playground	○	○	○	○	○
8. Running and cycling track	○	○	○	○	○
9. Fitness area	○	○	○	○	○
10. Swimming pool	○	○	○	○	○
11. Skateboard area	○	○	○	○	○
12. Skating rink	○	○	○	○	○
13. Water sport	○	○	○	○	○
14. Open/Green space	○	○	○	○	○

Figure 3.2. The example of importance questionnaire

Subsequently, to obtain fuzzy intervals of importance for each criterion, experts were asked to assess the score intervals of importance on a scale of 0 to 25. For example, how many points would you consider each of “Very unimportant”, “Unimportant”, “Neutral”, “Important”, and “Very important” are each scored, and provide a numerical interval from 0 to 25 to indicate them. The scoring intervals are completely free and unrestricted, and the scoring intervals may be wide or narrow, and may or may not overlap. The response demonstration is shown in Figure 3.3 and Figure 3.4

1. Very unimportant	1	4
2. Unimportant	6	10
3. Neutral	12	17
4. Important	17	19
5. Very important	20	25

Figure 3.3. The example of fuzzy intervals questionnaire

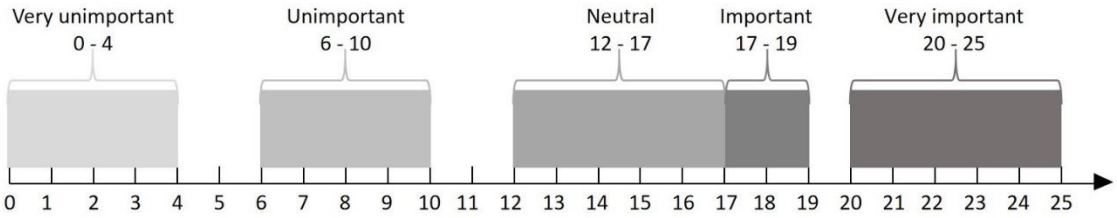

Figure 3.4. The example of the scoring intervals of importance

Invitation to experts. Subsequently, 74 experts from different disciplines such as urban design, public health, sports science, geography and transport were invited by email to complete this questionnaire. These experts were required to have at least one English peer-reviewed paper published on a relevant topic. The questionnaire was collected online between 3 May and 20 May 2023, and a total of 42 experts agreed to and completed the questionnaire anonymously, with a response rate of 56.8%.

Data analysis methodologies. In terms of expert questionnaire statistics analysis, the "double triangular fuzzy number" in the fuzzy Delphi method is less prone to compromise than the "single triangular fuzzy number", and has the effect of grey zone testing. Therefore, this study followed the "double triangular fuzzy number" developed by Jeng [107] to integrate expert opinions to screen important environmental criteria. The detailed calculation steps of this method can be found in Appendix 2. Based on the calculation steps of the fuzzy Delphi method, data from 42 expert questionnaires were analysed to screen out key park criteria that influence physical activity in the context of a dense urban area.

3.2.3 Quantitative audit items

After the identification and importance assessment of the environmental criteria of the park is completed, the next step is to convert the key criteria screened into measurable audit items. By quantifying the criteria into specific observable questionnaire items, each item can be completed and recorded by visual observation or simple assessment during field audits, enabling non-experts to independently complete the audit operation, thus enhancing the universality and practicality of dense urban park audit tool. This section discusses in detail the different aspects of the construction logic and scoring design of the audit items.

Structure logic of audit items. To ensure that each audit question was closely aligned with the audit objective, which was to assess the effect of the park's environmental criteria on physical activity, the ‘presence’ aspect of the environmental criteria was assessed. The ‘presence’ aspect of a criterion is a precondition for the possibility for residents to engage in

physical activity and reflects whether a park environmental attribute or facility that affects physical activity is present in the park [61]. For example, “Are there any traffic lights at the crosswalks?” and “Are there any public toilets in the park?”. However, relying on a single aspect of ‘presence’ alone is not sufficient to fully capture the potential effects of criteria on physical activity. For example, fitness equipment areas may “exist” in a park, but they may be too few, poorly maintained or under-utilised, which can seriously diminish their role in supporting residents' physical activity [75]. Therefore, to improve the coverage and sophistication of audit items, the environmental criteria affecting physical activity are assessed from various aspects, including “usage”, “quantity”, “quality”, “maintenance” and “condition” to capture a more detailed view of how different aspects of the park's criteria affect physical activity (as shown in Table 3.2).

Table 3.2. Different aspects of the criteria

Aspects	Descriptions	References
Presence	It is a precondition for the possibility for residents to engage in physical activity and reflects whether a park environmental attribute or facility that affects physical activity is present in the park.	[12, 46]
Usage	It reflects the real value of facilities and the actual response of residents to environmental facilities and is a key aspect in transforming potential support into actual behaviour.	[12]
Quantity	It is a measure of the number of facilities, the spatial distribution of density, and the size of the population that can be served and is a key aspect of the assessment of the capacity of the criteria in supporting residential physical activity.	[39, 75]
Quality	It is an important aspect that affects the user experience and intention to reuse, including the level of design sophistication, material quality, functional diversity and aesthetics of the facilities.	[40, 75]
Maintenance	It reflects the attention given by the management to the facilities and user experience. Even if the facilities are complete and in sufficient quantity, if they are in poor maintenance or in serious disrepair, it would reduce the intention and frequency of residents to use the facilities or even cause safety incidents.	[18, 46]
Condition	It is a comprehensive aspect of the criteria and is used to assess the current overall condition of the criteria.	[18, 39]

By assessing the criteria for park environments from these six different aspects in an integrative way, it effectively compensates for the lack of information brought about by previous tools that relied only on the “presence-absence” dichotomy of judgement. Especially in the context of dense cities, where land resources are tight and the spatial distribution of facilities is concentrated, this multi-aspect assessment of the criteria is an invaluable reference for the development of strategies to improve optimization of facilities allocation.

Scoring design of audit items. Two main scoring mechanisms were used to adapt to different types of audit tool items: a dichotomous scale and a 3-point Likert scale. The dichotomous scale is used for judgemental questions such as the presence or absence of certain facilities or functional areas in a park. Responses are in the format of "No/Yes" or "Absent/Present" and are assigned a value of 0 or 1, respectively. For example, "Are there any drinking fountains in the park?" scores 1 if the presence of drinking fountains is observed and 0 if it is not. A three-point Likert scale is used for questions of degree, ranging from 0 to 2, corresponding to "None", "Some", and "A lot". For example, "Are the shelters and pavilions in good condition?" is based on the overall condition of the facility, scoring 2 if shelters are in good condition, 1 if they are in fair condition, and 0 if they are mostly broken. These two scoring systems are simple and clear, ensuring operability and avoiding the excessive influence of the auditor's subjective judgement, and are appropriate for independent implementation by non-professionals.

The scoring of audit tool items also provides a mechanism to deal with some negative environment attributes. Several environmental attributes such as litter, noise, and obstacles may play a negative role in the use of parks for physical activity by residents, especially in dense urban contexts [48]. For example, "Are there unauthorised graffiti in the park?", based on an on-site audit, is scored as 0 if the observation is 'yes', and 1 if it is not using a dichotomous scale. For instance, "Are there any obstacles on the path?" is reverse scored on a 3-point Likert scale according to the level of this item. This negative scoring mechanism not only enhances the ability of audit tool to identify environmental barrier attributes but also alerts managers to critical issues such as park maintenance and management.

Additionally, multiple-choice questions and open-ended comments were also considered in the scoring design of audit tool. Considering the complexity and geographic variation of some environmental attributes, audit tool introduced multiple choice questions and open-ended comment areas along with the scoring questions. Multiple choice questions such as "What types of sports courts are in the park?" facilitate detailed documentation of the presence of multiple forms of facilities in the park. Furthermore, the open-ended comments facilitate the collection of additional auditor comments on the scoring items. The design of these scoring mechanisms enhances the flexibility and scalability of the audit tool, allowing it to be more relevant to the actual field environment and providing objective data for subsequent research.

3.2.4 Pilot test

To further optimise the audit items and validate their applicability and operability in a realistic environment, a pilot test of the initially developed audit tool items was conducted. The purpose of the pilot test was to provide reality-based information for improving the draft audit items. This subsection describes the pilot testing process in detail.

Case selection and rationale. Dense urban park audit tool was developed specifically to assess the environmental attributes of parks in dense urban areas, and therefore, the dense urban

area of Tokyo, Japan was used as a pilot test site. According to the Statistics Bureau of Japan [108], a basic unit area with a total population of more than 5,000 and a population density of more than 4,000 or more people per square kilometre is defined as a Densely inhabited district. Also, an urban area with a population density of more than 1,500 people per square kilometre is considered to be a dense urban area [58]. Therefore, four dense urban area, Arakawa (21405 persons per square kilometre), Shinjuku (19175.9 persons per square kilometre), Setagaya (16256.1 persons per square kilometre), and Koto (12196.1 persons per square kilometre) in Tokyo, Japan were used as pilot test sites [109]. Four parks were selected as case studies among these four areas: Hanegi park (8.12 hectares), Shinjuku central park (8.8 hectares), Shioiri park (12.9 hectares), and Sarue park (14.5 hectares) (shown in Figure 3.5).

Figure 3.5. Case map of the pilot test

(source: Google Earth).

These four parks are in typical dense urban areas of Tokyo, Japan, with high population densities. For example, Shioiri park is located in Arakawa Ward, which has a population density of 21,405 persons/km². These four parks have a diversity of neighbourhood environments. For example, Shinjuku central park in Shinjuku Ward has a neighbourhood of mainly commercial buildings, Hanegi park in Setagaya Ward has a neighbourhood of residential buildings, and Shioiri park in Arakawa Ward has a neighbourhood of riverside views.

Regarding park size, on the one hand, using small parks as a test case for audit tool may not capture most of the audit items to provide real information for their modifications, which may lead to measurement bias in audit tool. On the other hand, in dense urban areas with high population densities and a lack of open space, oversized parks are uncommon and not representative. The four park cases are moderate in size, large enough to cover all audit items but not too large to cause non-representative bias. Details of the parks are shown in Table 3.3.

Table 3.3. Details of the park cases.

Park name	**Size (hectares)**	**Location**	**Population density (persons/km²)**
Hanegi park	8.12	Setagaya Ward	16,256.1
Shinjuku central park	8.8	Shinjuku Ward	19,175.9
Shioiri park	12.9	Arakawa Ward	21,405.0
Sarue park	14.5	Koto Ward	12,196.1

Pilot audit process. Prior to the on-site audit, the location and boundaries of the pilot case were confirmed using Google Earth, and a map of the pilot case was created, as shown in Figure 3.5. Additionally, the official opening webpage of the pilot test park was visited to obtain additional information, including the location and number of park entrances, barrier-free access, opening hours, related facilities, and information on special events. This material was printed and carried over to the pilot case site audit along with the initial audit tool audit items.

The pilot test was conducted between 11th and 12th June 2023 with two trained auditors. Both auditors entered the same park at the same time and independently observed and scored the park with a paper version of the audit tool in hand. Firstly, the auditors were asked to record relevant information such as park name, date, weather conditions and audit start time in the audit tool. Subsequently, park attributes such as infrastructure (e.g., benches, shelters, and restrooms), and activity areas (e.g., children's playgrounds, athletic fields, and fitness areas) were reviewed for the pilot test based on the audit tool items (as shown in Figure 3.6). Finally, auditors were asked to ensure that all audit items were completed and to document the audit

end time. Additionally, auditors were asked to record and retain photographs associated with the audit items, which provided a visual supplement to subsequent discussions of revisions to the audit items.

Figure 3.6. Park attributes audited by the pilot test park

The pilot test not only validated the applicability of audit tool in a dense urban park environment but also provided a realistic basis for its optimisation. The results of the pilot test revealed potential directions for improvement in various aspects such as scoring design and item definition. Based on the pilot test, audit tool can be further improved and finally finalised to form a set of well-structured, comprehensive and operational park audit tools.

3.2.5 Revision of audit tool

Following the completion of the pilot test, a series of systematic revisions were carried out in this study aimed at optimising the initial audit tool version based on site observations

and auditors' feedback. The revision process of audit tool is shown in Figure 3.7. The pilot test was conducted independently by two trained auditors in four medium- and large-sized parks in Tokyo. After completing the on-site audits, the two auditors each wrote a detailed observation record.

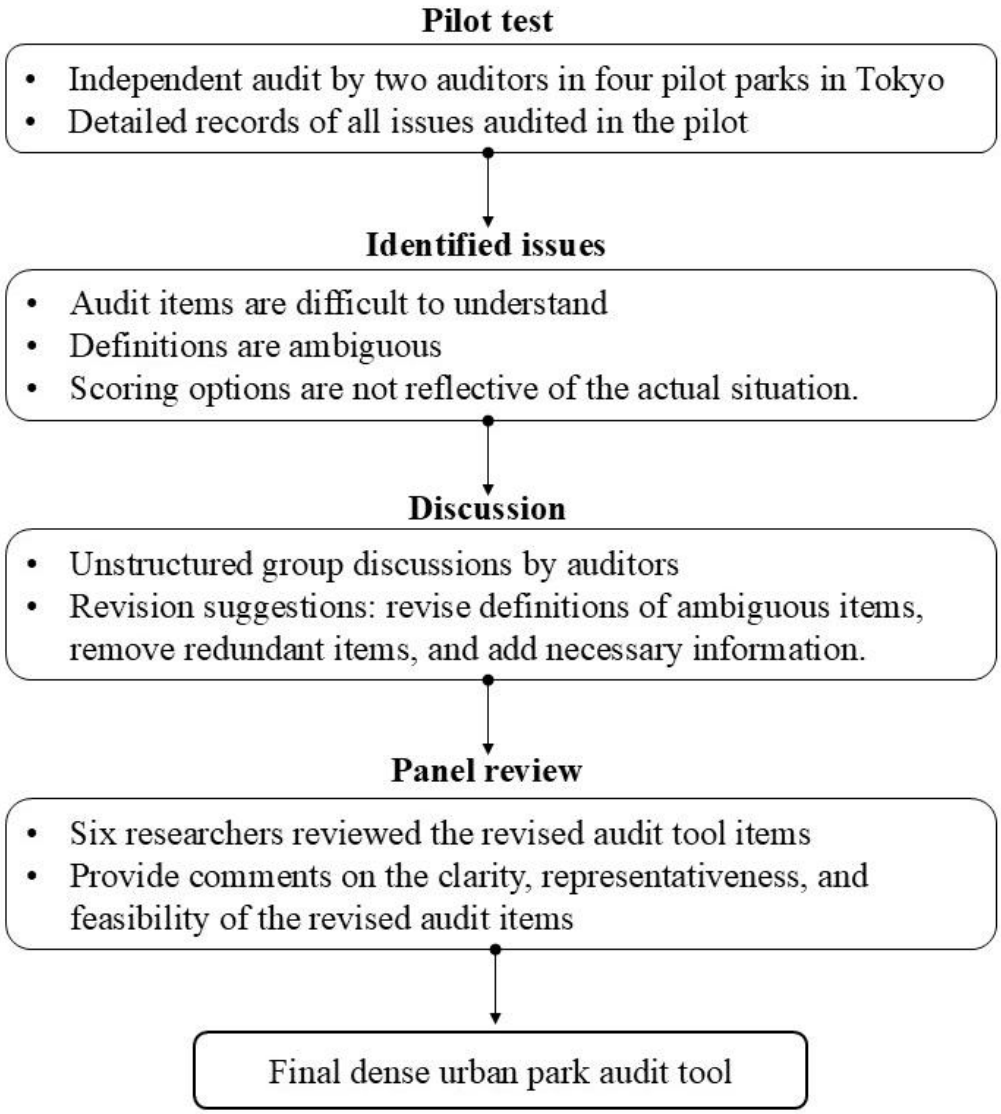

Figure 3.7. The revision process of dense urban park audit tool

An unstructured discussion was conducted after the pilot test. During the discussion, the auditors reviewed each audit item and discussed those marked as difficult to understand in definition, not easy to score and repetitive in content. Based on these issues, the auditors suggested corresponding revisions, which included correcting ambiguous audit items, deleting or redefining duplicated items and supplementing missing but necessary information in the on-site audit.

After completing the initial dense urban park audit tool items revision, an advisory panel

of six researchers with professional backgrounds in urban design, public health and sports science formed to conduct an independent assessment of the revised audit tool. The advisory panel provided expert advice on the clarity of the definition of items, the appropriateness of the scoring scale, and a judgement on whether the audit tool items captured the level of support for physical activity among residents in dense urban settings. These revisions aim to improve the clarity of the audit tool.

3.3 Results of audit tool development

This subsection follows the sequence of the audit tool development process and presents the main results of the five sections of the audit tool development process: (1) results of the initial framework development; (2) results of the significance scoring and screening criteria; (3) results of the quantitative audit item design; (4) observations and feedback from the pilot test; and (5) the revision process and final components of audit tool. These results provide the basis for further testing of audit tool 's reliability and validity in the subsequent chapters and provide foundational support for the future application of audit tool in dense urban settings.

3.3.1 Results of the preliminary framework

Based on a systematic literature review, this study developed a preliminary environmental assessment framework for assessing dense urban parks that impact on residents' physical activity. The framework consists of five dimensions, and a total of 31 environmental criteria were identified. The five dimensions are: park surroundings and accessibility [88, 98], activity areas [75], facilities and amenities [40, 62], aesthetics [90, 99], and safety [50, 100].

In the park surroundings and accessibility dimension, a total of five criteria are included: entrance points and signs, traffic safety, park boundaries, public transport stations, and parking lots, focusing on the role of these criteria in affecting residents' convenience in accessing the park. For example, park entrances and parking lots have a direct impact on the convenience of residents accessing the park, while traffic lights, pedestrian crossings and traffic management ensure that the residents have a sense of safety when they visit the park.

A total of nine criteria were identified in the activity area dimension, including sports courts, playgrounds, running/cycling tracks, fitness areas, skateboarding/skating areas, and water sports areas. These criteria cover a wide variety of space types that support physical activity for different populations, such as playgrounds for children's activities and outdoor fitness areas used by the elderly. These activity areas not only directly provide places for physical activity, but their quality, management and maintenance also deeply affect the frequency of use.

A total of nine criteria are in the facilities and amenities dimension, including trails, public toilets, drinking fountains, benches, trash cans, vending machines, and so on. These park

facilities and amenities emphasise the supplementary effect on activity support and play a key role in ensuring continuity of activities and enhancing comfort of use.

Five criteria are included in the aesthetic characterisation dimension, including water feature, landscape, public art, litter and graffiti. These criteria have been shown to be important factors in increasing people's frequency of park use and length of stay. For example, good landscaping and well-managed water bodies help create a pleasant atmosphere, which in turn motivates residents to frequently access parks to trigger physical activity.

The last dimension is safety, which includes lighting, surveillance equipment, emergency facilities and warning signs. The good condition of these criteria creates a high level of perceived safety for residents such as women, the elderly and children, which is a key precondition for encouraging them to participate in physical activities in the park.

The above criteria create a comprehensive assessment framework that captures the relationship between the park environment and physical activity from a variety of perspectives and provides a framework for the development of a quantitative audit items.

3.3.2 Results of key criteria

This subsection presents the expert evaluation of the importance of the 31 criteria. A total of 72 experts were invited to participate, all of whom had professional backgrounds relevant to urban design, environmental behaviour, public health, or sports and leisure studies. Of these, 42 completed questionnaires were received. According to the data processing steps of the fuzzy Delphi method, the maximum, minimum, and double standard deviation of the criterion were summarised and calculated for each questionnaire. Those questionnaires with criteria whose maximum or minimum values fell outside the double standard deviation were excluded. A total of 27 effective questionnaires were ultimately retained. Of these 27 effective questionnaires, the Consensus value was calculated for each criterion and used to determine the importance of each criterion and its inclusion in the audit tool. The statistical results of the importance of the 31 criteria are shown in Table 3.4.

Table 3.4. The consensus values of criteria

Criteria	Conservative value		Optimistic value		Geometric mean		Verification values	Consensus values
	Min	Max	Min	Max	Con[a]	Opt[b]		
Entrance points and sign	2.8	4.2	3.8	5.0	3.31	4.16	0.46	3.92
Traffic safety	3	4.2	3.8	5.0	3.74	4.64	0.50	4.06
Park boundary	2.4	4.2	3.4	5.0	3.29	4.17	0.08	3.77
Public transport station	2.8	4.0	3.8	5.0	3.32	4.20	0.68	3.87
Parking lot	1.8	3.4	2.8	4.4	2.56	3.45	0.29	3.06
Sport court	2.4	4.2	3.4	5.0	3.36	4.25	0.09	3.80
Playground	2.8	4.2	3.8	5.0	3.71	4.62	0.51	4.05
Running and cycling track	2.4	4.2	3.4	5.0	3.42	4.29	0.08	3.83
Fitness area	2.2	3.8	3.0	4.4	2.93	3.77	0.04	3.38
Swimming pool	1.0	2.6	2.0	3.4	1.80	2.67	0.27	2.27
Skateboard area	1.8	3.4	2.8	4.4	2.54	3.39	0.26	3.04
Skating rink	0.8	2.6	1.8	3.4	1.55	2.44	0.09	2.11
Water sport	0.8	2.6	1.8	3.4	1.74	2.62	0.08	2.19
Open/green space	3.0	4.4	3.8	5.0	4.00	4.90	0.31	4.24
Path	3.0	4.4	3.8	5.0	3.95	4.85	0.30	4.22
Public toilet	2.4	4.2	3.4	5.0	3.73	4.63	0.11	3.98
Shelter and pavilion	2.0	4.2	3.4	5.0	3.35	4.24	0.09	3.80
Drinking fountain	2.8	4.2	3.8	5.0	3.60	4.48	0.48	4.01
Vending machine	0.8	2.4	1.6	3.4	1.54	2.42	0.07	1.99
Bench	2.8	4.4	3.8	5.0	3.72	4.58	0.26	4.12
Picnic table	2.0	3.8	3.0	4.4	2.88	3.74	0.06	3.36
Trash can	2.8	4.4	3.6	5.0	3.62	4.46	0.04	4.02

Water feature	2.0	3.2	2.8	4.0	2.56	3.36	0.40	2.99
Vegetation and landscape	3.0	4.4	3.8	5.0	3.84	4.73	0.28	4.18
Public art	1.0	3.2	2.4	4.2	2.51	3.36	0.04	2.87
Graffiti	1.8	3.4	2.8	4.4	2.60	3.46	0.25	3.07
Litter	2.8	4.0	3.8	5.0	3.35	4.22	0.68	3.88
Lighting	3.0	4.2	3.8	5.0	3.55	4.41	0.46	3.99
Surveillance equipment	1.8	3.4	2.8	4.4	2.63	3.52	0.30	3.09
Emergency device	1.8	3.4	2.8	4.4	2.66	3.51	0.25	3.09
Warning sign	1.8	3.4	2.8	4.4	2.55	3.41	0.26	3.05

Note. a: geometric mean of conservative value; b: geometric mean of optimistic value.

A five-point scale (from 1 = very unimportant to 5 = very important) was used to assess the importance of the 31 criteria. In this study, a score of 3.0 was established as the threshold value, representing a neutral level of importance. Therefore, any criterion with a consensus value above 3.0 was considered important for supporting physical activity in dense urban contexts and was retained in the final audit tool framework.

The results showed that a total of 25 environmental criteria achieved a consensus value exceeding the 3.0 threshold and were therefore included in audit tool. Conversely, six criteria failed to meet this standard: “Swimming pool” (2.27), “Skating rink” (2.11), “Water sport” (2.19), “Vending machine” (1.99), “Water feature” (2.99), and “Public art” (2.87), as presented in Table 3.5.

The relatively low consensus values for these six criteria indicate that experts perceived them to have limited practical effectiveness in promoting physical activity within dense urban environments. For example, some activity areas such as “swimming pools” or “water sports” may be difficult to achieve because of the high space requirements and high construction costs in dense urban contexts. Additionally, “public art” or “water features”, while enhancing the aesthetics of parks, may not have enough direct relevance to physical activity in dense urban contexts, leading to their exclusion from the framework.

Table 3.5. Criteria excluded from the framework

Dimensions	Exclusion criteria	Consensus value
Activity areas	Swimming pool	2.27
	Skating rink	2.11
	Water sport	2.19
Facilities and amenities	Vending machine	1.99
Aesthetics	Water feature	2.99
	Public art	2.87

Amongst those 25 criteria that were retained, there was the highest level of agreement on the importance of “Open/Green space” and “Paths”, with consensus values of 4.24 and 4.22 respectively (as shown in Table 3.6). These results indicate that the provision of flexible spaces for a variety of physical activities, as well as a good system of pathways, are key foundations for encouraging residents to access parks and promote physical activity in dense urban settings [58]. Furthermore, in addition to important activity spaces such as Open/Green space and Paths, the expert consensus-based results indicated that the positive impact of supportive amenities on physical activity behaviours is also highly valued [24]. For example, amenities such as “drinking fountains”, “benches” and “trash can” have consensus values of 4.01, 4.12, and 4.02,

respectively. These criteria have had a positive impact on residential use of parks, promoting and supporting physical activity.

Table 3.6. High level of agreement of criteria

Dimensions	Criteria	Consensus value
Park surroundings and accessibility	Traffic safety	4.06
Activity areas	Playground	4.05
	Open/Green space	4.24
Facilities and amenities	Path	4.22
	Drinking fountain	4.01
	Bench	4.12
	Trash can	4.02
Aesthetics	Vegetation and landscape	4.18

In conclusion, through the expert assessment of the importance of the framework criteria, and the analysis of the expert consensus values by the fuzzy Delphi method, this study systematically screened 25 environmental criteria that have a significant impact on facilitating residents' park-related physical activities in dense urban areas. These criteria covered multiple dimensions of park surroundings, park activity areas, amenities, safety, and aesthetics. Table 3.7 shows the full assessment framework after the screening process. The results of this scoring support the quantification of audit items and development of audit tool for the next stages. The next step in the study will be to transform these criteria into a quantifiable environmental audit item for parks.

Tabel 3.7. The full framework of dense urban park audit tool.

Dimensions	Criteria	Consensus values
Park surroundings and accessibility	Entrance points and sign	3.92
	Traffic safety	4.06
	Park boundary	3.77
	Public transport station	3.87
	Parking lot	3.06
Activity areas	Sport court	3.80
	Playground	4.05

	Running and cycling track	3.83
	Fitness area	3.38
	Skateboard area	3.04
	Open/green space	4.24
	Path	4.22
	Public toilet	3.98
	Shelter and pavilion	3.80
Facilities and amenities	Drinking fountain	4.01
	Bench	4.12
	Picnic table	3.36
	Trash can	4.02
	Vegetation and landscape	4.18
Aesthetics	Graffiti	3.07
	Litter	3.88
	Lighting	3.99
Safety	Surveillance equipment	3.09
	Emergency device	3.09
	Warning sign	3.05

3.3.3 Results quantified for audit items

This subsection presents the results of the quantitative audit items. It contains item designs for different aspects of each criterion, types of scoring scales, application and examples of scoring types. Based on the preliminary assessment framework and the establishment of the 25 important criteria, the design procedure took full consideration of the role of the different aspects of each criterion in the promotion of physical activity, and between one and four quantitative audit items were designed for each criterion, resulting in the creation of 88 measurable audit items (as shown in Table 3.8).

Table 3.8. Different aspects of the criteria

Dimensions	Criteria	Aspects
Park surroundings and accessibility	Entrance points and sign	Number of entrances, entrances signage, and attractiveness of entrances.
	Traffic safety	Crosswalks, traffic lights, speed limit signs, and traffic situation.
	Park boundary	The presence, width suitability and access barriers of sidewalks/bike lanes.
	Public transport station	Assessment of public transport station distribution and walking/cycling accessibility.

Activity areas	Parking lot	Presence of parking lots, number of parking spaces and bike racks, fees and convenience
	Sport court	Record aspects such as type, usability, free access and management of sports courts.
	Playground	Playground presence, availability, instruction in use and management.
	Running and cycling track	Running and cycling track presence, availability, instruction in use and management.
	Fitness area	Fitness area presence, availability, instruction in use and management.
	Skateboard area	Skateboard area presence, availability, instruction in use and management.
	Open/green space	Open/green space presence, availability, instruction in use and management.
Facilities and amenities	Path	Evaluate aspects of path presence, suitable widths, obstacles, and maintenance.
	Public toilet	the presence, the objects provided and maintenance of public toilet.
	Shelter and pavilion	Assessment of Shelter and pavilion in terms of presence, benches provided and maintenance.
	Drinking fountain	The presence and availability of drinking fountain.
	Bench	Evaluate the presence, shade, landscaping provided, and maintenance of the bench.
	Picnic table	The presence, shade, and condition aspects of picnic table.
	Trash can	Evaluate aspects of trash can's presence, ease of finding, and condition.
Aesthetics	Vegetation and landscape	Vegetation and landscape in terms of number of species, management and condition.
	Graffiti	The presence of graffiti
	Litter	The presence of litter
Safety	Lighting	Adequacy of lighting
	Surveillance equipment	The presence of surveillance equipment
	Emergency device	The presence of emergency devices and marking it on a map
	Warning sign	Presence and clarity of warning signs

Following this, different types of rating scales were designed based on the characteristics of the different aspects of the criteria, including: a dichotomous scale (Yes/No) and a three-point scale (None/Some/A lot). The dichotomous scale had 57 items accounting for 64.8%. For example, “Are there any signs showing the location or directions to the park?”, the answer will

be 0=No or 1=Yes. The three-point scale had 30 items accounting for 34.1%. For example, “Is the traffic situation around the park generally safe for residents?”, the answer will be 0=none, 1=some, 2=a lot. Additionally, multiple choice questions and open-ended comment areas were also designed for audit items. Multiple choice questions such as “What types of sports courts are in the park?” facilitate detailed documentation of the presence of multiple forms of facilities in the park. Open-ended comments were established for 25 criteria to collect additional comments from auditors on items. The different scoring types have targeted adaptations based on different aspects of the criteria's characteristics, as shown in Table 3.9.

Table 3.9. Application and Example Items for different scoring types

Scoring types	Number of items	Applicable aspects	Items
Dichotomous scale (Yes/No)	57	Assessing the presence and usability of items.	Are there any traffic lights at the crosswalks?
Three-point scale (None/Some/A lot)	30	Assessing the extent and quality of items, such as maintenance status, attractiveness, shade coverage.	Are the sports courts in good condition?
Multiple choice questions	1	Assessing the multiple types of items in the environment.	What types of sports courts are in the park?
Open-ended comments	25	Used to collect additional comments from auditors on items	N/A

To make the audit tool more refined and used-friendly, an advisory panel of six researchers with professional backgrounds in urban design, public health and sports science was invited to discuss the feasibility of audit items. During the discussion they provided inputs for the revision and scaling down of the 88 items. For instance, considering the audit tool is for common auditors, more simple sentences are designed to describe items, “Are there traffic lights on the intersection access to the park?” is modified to “Are there any traffic lights on the crosswalk?” In addition, given the variation in the size and capacity of parking lot, two audit items: “Are there parking lots in the park?” and “How many parking lots are in the park” were combined into one audit item: “Are there any parking lots in the park?” Answer either no or yes, while an open-ended comment is added following the "yes" answer to audit the number of parking spaces. Finally, the items for benches and shelters in the “Public /Green spaces” criterion were deemed to be duplicates of the “Bench” and “Shelter and pavilion” criteria, and both items were removed. The draft of the audit tool consists of six sections recording basic information of the park, surroundings and accessibility, activity areas, facilities and amenities, aesthetics, and safety with a total of 86 items, and was used for the pilot test.

3.3.4 Results for pilot test

This subsection details the key findings of the pilot test. To further and validate the applicability and operability of the audit items in a dense urban park environment, a pilot test was conducted in June 2023 in Tokyo, Japan. Four pilot test parks (Hanegi park, Shinjuku central park, Shioiri park, and Sarue park) were selected and successfully completed on-site audits of the initial version of the audit tool. The pre-prepared park maps, official website information, and printed audit sheets played an important role in the efficient and orderly data collection during the pilot test. The auditors were able to complete the observation and scoring of 86 audit items in one on-site visit, confirming the basic feasibility of the audit tool item for application in dense urban settings.

Following the pilot test, we calculated the time spent on site audits. Depending on the size and scale of each park, their audit times varied, ranging roughly between 1.5 and 2.5 hours. In addition, the information collected during the pre-audit period, such as park maps and official website information, significantly reduced the time required for on-site location and information confirmation.

The results of the pilot test showed that most of the audit items showed good understandability and operability in the substantive environment. Based on the feedback from the auditors in the open-ended questions, there are still issues that need to be improved for the audit items, summarised as follows: 1) The definitions of some of the items appeared to be repetitive, with multiple corresponding objectives in the physical environment, such as benches and shelters. Therefore, further definitional clarity is required for these items to differentiate between targets or types in different areas of the substantive environment; 2) Some items for more rare facilities, such as emergency equipment and surveillance devices, are not always quickly observable in the park. It is suggested that operational instructions or changes to the description of audit items need to be provided.

3.3.5 Results of audit tool revision

This section describes the process of revising and optimising the audit tool on introduction, specification of use, item settings and overall structure based on the results of the pilot test. Through the analysis of the pilot data and feedback from the auditors, this study made the necessary improvements to audit tool to enhance its practicality, operability and scientific, and finalised the final version of the audit tool. The full version of audit tool is available in Appendix 3.

Supplement for introduction and usage requirements. To further enhance the standardised procedures for audit tool use, the introductory section and the requirements for use of audit tool were first revised. The following additions were made to the original: 1) Clarification of audit tool objectives: it was clearly stated that the main use of audit tool is to

assess park environments in dense urban areas affecting physical activity, and the value of its application in urban health promotion and environmental intervention research was emphasised; 2) Standardisation of the operational procedures: specific instructions for pre-audit preparations (including understanding the park information, and preparing the paper version of audit tool), on-site audit steps (including time recording, item-by-item scoring, and taking photos to record the item's physical condition), and post-audit data organisation were added.

Revision of audit items. Based on the auditors' on-site audit experience and feedback, the definition and content of the audit tool audit items have been revised, including the following aspects:1) optimisation of audit item definitions. The pilot test showed that the definitions of some items were ambiguous or misunderstood, which affected the consistency of the auditors' judgement. To address this issue, the definitions of items were revised and clarified. For example, the original "Is the entrance signage there?" was revised to "Are there any signs showing the location or directions to the park?", to make it clearer that it refers to the direction or location signs visible in the field; 2) adjustment and replacement of items. During the pilot test, some items were found to deviate from the reality of the parks in a dense urban context, and necessary adjustments were made. For instance, the original "Cycling track" item was not observed because bicycles were generally not allowed in the pilot test parks. For this reason, it was decided to make "Cycling track" an alternative item, which was only evaluated in parks where cycling-related facilities existed. Additionally, the pilot parks did not have a dedicated skateboarding area, and signs prohibiting skateboarding were commonly posted. Therefore, the former "Skateboard area" criterion was also adjusted to an optional item to accommodate different site conditions; 3) deletion of items that cannot be audited. Considering that the auditors were unable to assess the actual conditions of some items, including lights, surveillance equipment and emergency devices through individual competence, it was decided that the relevant items were deleted. This helped to improve the operability of the audit and the reality of the data and avoided the bias of the auditor due to subjective speculation.

Final version of audit tool structure. After systematic revision and optimisation, the final version of audit tool contains a total of 74 audit items, of which 17 items were in the park surroundings and accessibility dimension, 23 items in the activity areas dimension, 23 items in the facilities and amenities dimension, 5 items in the aesthetics dimension and 6 items in the safety dimension. The structure of audit tool is shown in Figure 3.8.

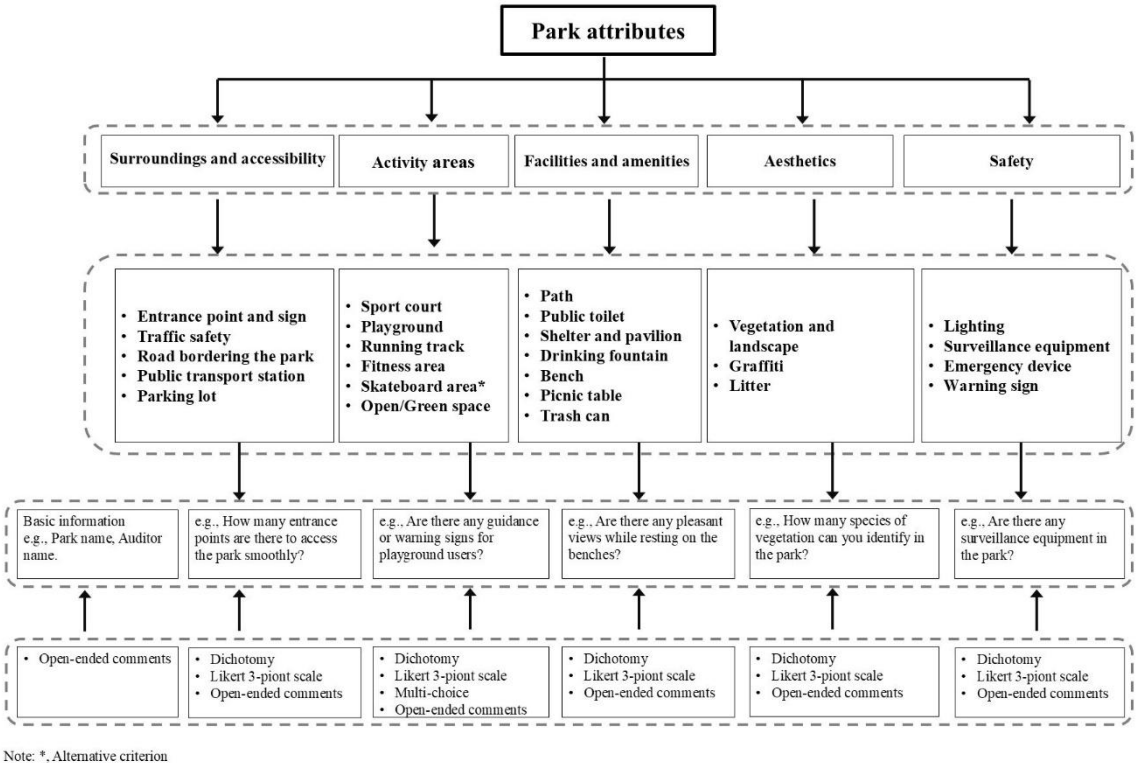

Figure 3.8. The final structure of dense urban park audit tool.

3.4 Discussion of audit tool development

An audit tool is an objective method for assessing environmental attributes. While several park environmental audit tools have been developed, this study develops audit tool was specifically designed to assess park attributes to promote park-related physical activity in dense urban areas by addressing the unique challenges faced in Asian dense urban areas.

The systematic literature review identified gaps in existing tools, and the development of audit tool fills this gap by providing a framework specifically designed for the limited open space, high population density environments common to many Asian cities. Additionally, the simplicity of audit tool makes it suitable for a wider range of users, such as non-experts.

3.4.1 Applicability of the audit tool framework

Dense urban park audit tool was developed based on group decision-making by experts from diverse disciplines. The park environmental criteria in the audit tool were considered important in supporting physical activity in dense urban areas, with particular importance for the criteria the “Open/Green space” and the “Path” according to the consensus value by experts.

These results are in line with previous systematic reviews indicating that park attributes such as green space and paths are convincingly supported in promoting park-related physical activity [19, 22].

However, although some of the environmental criteria were considered valid in the group decision-making, these were used as optional criteria or items in the final version of the audit tool as they were not applicable to this geographic context. For instance, skateboarding-related sports are known to be one of the most popular recreational activities in parks in Western countries or regions and play a supportive role in the physical activity, health, and well-being of young people [110]. According to the expert consensus, "Skateboarding areas" are identified as a valid park criterion to support park-related physical activity (consensus value = 3.04). Nevertheless, in the pilot test parks, it was observed that there was a lack of designated areas for skateboarding activities, or skateboarding was explicitly prohibited within the parks. Therefore, users of the audit tool are encouraged to adjust the audit items according to their specific geographical contexts to enhance the applicability of audit tool.

In addition, related to transport planning in different urban contexts, some roads around the pilot parks do not have dedicated bike lanes, resulting in cyclists frequently using sidewalks or main roads. The lack of bike lanes may raise safety concerns and have a negative impact on individuals attempting to access the parks by bicycle. For instance, a study reports that bicycle-related traffic accidents in dense urban areas often have serious consequences [111]. Thus, when the audit tool is employed to assess environmental criteria for supporting park-related physical activity in a particular geographical context, it could provide evidence of context-specific realities for policymakers in (re)designing park interventions.

3.4.2 Innovations and Advantages of audit tool

Dense urban park audit tool framework consists of five dimensions, 24 environmental criteria, and 74 audit items. This structure provides both flexibility and specificity, allowing adaptation to various contexts while maintaining a strong focus on dense urban settings. Unlike existing audit tools such as CPAT[64], POST [91], and EARPS [62], dense urban park audit tool was explicitly designed to address the physical constraints and environmental challenges characteristic of high-density urban areas, particularly in Asia. For instance, our audit tool evaluates factors often overlooked by previous tools, such as whether sports courts within parks are freely accessible or require payment—an important consideration in densely populated cities where demand for recreational facilities is high. Dense urban park audit tool identified that certain features commonly included in other tools, such as bicycle lanes and skateboarding areas, may be less relevant in high-density settings due to the limited availability of free space and cultural differences that influence the types of physical activities preferred in these areas.

Another key innovation of dense urban park audit tool is the integration of the fuzzy Delphi method during its development. This methodological approach enabled the systematic collection and synthesis of expert consensus on the most contextually relevant criteria,

enhancing the tool's validity. Furthermore, dense urban park audit tool was developed with cultural adaptability in mind, particularly for urban contexts in Asia. By considering local cultural and social norms that influence park use, dense urban park audit tool ensures that its audit items are not only physically appropriate but also socially relevant. Additionally, its user-friendly design makes it accessible to non-expert users, such as community members and local stakeholders, distinguishing it from many existing tools that primarily target academic researchers. By broadening its user base, dense urban park audit tool supports the development of urban park environments that better align with the diverse needs and preferences of dense urban populations.

3.4.3 Considerations for audit tool application

There are several considerations in using dense urban park audit tool. First, it was necessary to provide training to the auditors prior to using dense urban park audit tool. Auditor training typically involves familiarisation with audit tools and conducting on-site audits [112]. The training of auditors has been shown to improve the reliability assessment of the tool, particularly items related to precepted attributes, such as perceived safety, aesthetics, and attractiveness [18]. Second, it is recommended that auditors pre-review the official website of the study case in advance, where some relevant information about sport facilities and activity events are usually provided [48]. This can enhance the auditor's understanding and knowledge of the park. However, the information that can be obtained through this approach is likely to be less available for smaller parks or parks that are not historically significant. Third, it is recommended that at least two auditors conduct independent audits of the study parks and aggregate the audit results to test inter-auditor reliability [50]. Lastly, there is the potential to adapt this audit tool for online use, which may be more attractive to professionals as it is less burdensome in terms of time and resources for data collation [113].

3.5 Summary

This chapter discusses the development of dense urban park audit tool, an audit tool for assessing park environments in dense urban areas. Parks are important destinations to support an active lifestyle, especially in densely populated urban areas lacking public open spaces. The development of dense urban park audit tool effectively addresses the unique challenges of dense urban environments, and the use of dense urban park audit tool for objective measurements improves the efficiency of evaluating the attributes of parks that support physical activity. Its inclusiveness allows community managers, local experts, urban designers, and landscape architects to utilize it and be better informed when advocating for positive park interventions. This will help promote the transformation of existing parks in dense urban areas and support residents in engaging in physical activity and active lifestyles.

Chapter 4 Testing of audit tool

4.1 Introduction

Following the completion of the development of the dense urban park audit tool, this chapter describes the reliability and validity testing of dense urban park audit tool. The testing of the audit tool aims to validate the reliability and validity of audit tool through on-site application, data collection and analysis, to ensure that the audit tool can accurately and comprehensively assess park environments affecting physical activity in dense urban environments. Reliability and validity validation is not only a critical step for audit tool, but also a necessary part of ensuring its scientific validity and broad applicability. Through validation, it is possible to identify the credibility of the audit tool items in assessing the environmental attributes, and the performance of the environmental attributes in supporting physical activity, thus providing an objective data base for further environmental renewal and optimisation.

Specifically, this chapter focuses on 1) the methodology of audit tool validation, including the selection of study sites, auditor training, on-site audits and data collection instruments, and statistical methodological modelling; 2) results of the audit tool reliability and validity, including reliability and validity at each dimension level and for each item; 3) a discussion of key findings of the validation process, and directions for improvement for future applications; 4) Summary. Through systematic testing and validation, audit tool shows very good reliability and validity, providing a scientific measurement method and decision-making basis for future environmental intervention and renewal in parks in dense urban areas.

4.2 Methods

This section systematically describes the methodology for the reliability and validity verification of audit tool, and the overview testing of audit tool included the following steps:1) study cases selection, including the definition of dense urban areas, the selection and characteristics of study cases; 2) auditor training, describing the training content and design process; 3) on-site audit and data collection procedures, detailing the audit process, audit tool use, and data collection strategy; 4) statistical model, describing the inter-rater reliability and gold standard used to evaluate reliability and validity. Through a systematic and standardized methodological process, the reliability and validity of the audit tool are scientifically and objectively verified.

4.2.1 Selection of study cases

This subsection describes the cases selection of the validation of audit tool. Dense urban park audit tool was developed specifically for the assessment of park environments in dense urban areas, and its target application scenario is parks in 'dense urban environments'. Therefore, the case selection criteria must be able to fully reflect the unique characteristics of dense urban areas in terms of population density, land use characteristics, and the diversity of socio-economic backgrounds, to ensure that the validation results are highly representative.

Definition and characterisation of dense urban areas. On a worldwide scale, population density has a significant impact on the urban spatial form and the lifestyles of their inhabitants [58]. Differences in urban population densities significantly influence urban spatial forms, and in general, Asian cities are generally more densely populated than most Western cities [58]. As a result, the spatial forms of Asian cities are also different from those of Western cities. For example, the population density in Tokyo (6,410 people/km^2) [114] is significantly higher than in Melbourne (521 people/km^2) [115], reflecting the typical compactness of Asian urban environments relative to Western cities. Figure 4.1 shows a comparison of population density between the Tokyo metropolitan area and the Melbourne area. As a dense urban area, compared to Melbourne, Tokyo is often faced with the challenges of spatial resource constraints, scarcity of green space, and high spatial overlap of people's activities, which places higher requirements on the planning and management of urban and public open spaces [58].

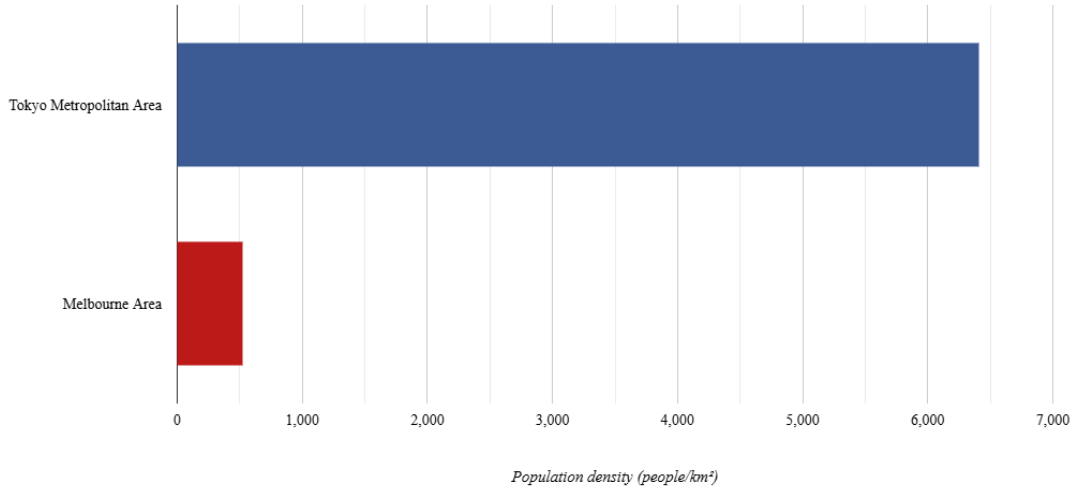

Figure 4.1. Comparison of population density between Tokyo and Melbourne

Dense urban park audit tool is a direct observational audit tool designed specifically for parks in dense urban areas. Therefore, in this study, the validation of audit tool was conducted

in densely populated areas of Tokyo based on the definition of densely inhabited districts by the Tokyo Metropolitan Government [116]. Densely inhabited districts is a basic unit area with a total population of more than 5,000 and a population density of more than 4,000 or more people per square kilometre [108]. The reliability and validity of audit tool was verified in a densely populated area of Tokyo, in line with the urban context in which audit tool was developed for dense urban areas. This ensures that the validation of audit tool is representative and that the study cases realistically reflect the characteristics of the reality of park environment in dense urban settings.

Establishment of park sample pool. The sample pool was created based on strict criteria and multidimensional considerations to reflect the diversity of park environment in dense urban environments. The sample pool data is derived from the Tokyo Metropolitan Administration's publicly available urban parks database, which lists 82 urban parks located in Tokyo. This park database is published by the Tokyo Metropolitan Parks and Green Spaces Department in a booklet called Tokyo Metropolitan Park Guide, the language of which is Japanese [117]. It is accompanied by relevant information such as area, main facility types, open status, and management organisations. The park database can be accessed from the following webpage (https://www.kensetsu.metro.tokyo.lg.jp/park/kouenannai/kouengaido).

The initial sample pool not only considered the geographical distribution of the parks but also integrated key variables such as the size of the parks, the quality of the facilities and the socio-economic status of the neighbourhoods to ensure a broad coverage of the sample in terms of spatial, physical and social attributes. As for geographical distribution, these park samples are widely distributed of the whole Tokyo, covering central urban areas, suburban urban areas, and areas along the river waterfront. This is shown in Figure 4.2.

Figure 4.2. Geographical distribution of the sample pool parks

(Source: Tokyo Metropolitan Parks and Green Spaces Department, Japan)

Concerning the size of the parks, these cover a range of scale levels from small neighbourhood parks (2.9 hectares) to large urban parks (204.4 hectares). This ensures a diversity of sample scales, ranging from relatively small, neighbourhood-type parks to large, regional parks, thus covering environmental features that support physical activity at different scales. However, these parks often have special functions or access requirements, and which will need to be further assessed for suitability for inclusion in a subsequent screening process.

Parks in the initial sample pool demonstrated greater heterogeneity in both the quantity and quality of facilities. Some parks are well-equipped with sports facilities, children's play areas, fitness equipment, shelters and barrier-free facilities, while others have more modest facilities or even lack basic infrastructural services. Moreover, depending on the theme of the parks, such as sports parks and children's parks, the functions of the services provided, and the types of facilities are different. By reviewing the official information, a preliminary categorisation of the status of facilities in each park has been made and will facilitate the subsequent screening process to consider the balance between functionality and diversity of the parks.

Additionally, socioeconomic status has been identified as an important factor influencing residents' health behaviours, park use and quality of life [118]. Therefore, socioeconomic status also was considered as a factor for screening parks in the sample pool. Socioeconomic status was assessed based on the areal deprivation index [119] , which is calculated from Japanese census data, and the neighbourhoods surrounding the sample parks were categorised into high socioeconomic status and low socioeconomic status areas. By introducing socioeconomic status, not only can we verify the applicability of audit tool under different environmental conditions but also provide a data base for future research on urban green space interventions based on a social equity perspective.

Sample screening and identification. The sample pool parks were screened by developing screening guidelines to ensure the representativeness of the selected park samples. First, the population density of Tokyo wards and municipalities was calculated based on the definition of densely inhabited districts, and parks located in non-densely inhabited districts areas were excluded to emphasize the need for the study to focus on dense urban environments. The function and theme of the park was considered. Those with a theme or function of cemeteries, temples and churches in green spaces were excluded. These types of spaces differ significantly from public parks in function, usage patterns and accessibility, and may disturb the standardised measurements of the audit tool. Park scale was also used as a screening indicator, considering the impact of park scale generation on the quantity and quality of park facilities. Small parks with an area of less than 5 hectares and large parks with an area of more than 50 hectares were excluded. Small parks usually lack sufficient supporting facilities for physical activity, such as sports courts, trail networks, and multi-purpose activity areas, due to

spatial constraints, and are not suitable for evaluating audit tool-covered full items. Additionally, large parks are not common in dense urban areas, which may result in an under representative sample. Finally, accessibility was used as the last screening criterion to ensure that the selected parks were free to enter, did not require reservations or payment of fees, and were open to the public most of the year. The screening criteria are summarised in Table 4.1.

Table 4.1. Summary of screening criteria for sample parks

No.	Screening criteria	Description of criteria	Exclusion basis and rationale
1	Urban density context	Target parks must be located within densely inhabited districts	Non-densely inhabited districts are inconsistent with the study's focus on dense urban environments.
2	Park function and theme	Exclude green spaces in cemeteries, religious parks such as temples or churches	These differ significantly from typical parks in function.
3	Park scale	Include medium-to-large parks ranging from 5 to 50 hectares.	Small parks lack diversity; large parks are uncommon in dense urban areas
4	Accessibility & Public Access	Parks must be open to the public without reservation or entrance fee.	Ensures selected parks meet the definition of public open space.

After a systematic screening of the sample pool, 25 eligible medium- and large-sized urban parks were identified as the final study cases. Table 4.2 summarises the names, park scale, address, size, population number, population density, and areal deprivation index of the area in which the parks are located. In spatial distribution, they cover a wide range of major areas in Tokyo's 23 wards with diverse neighbourhood, as shown in Figure 4.3. For example, there are central urban areas such as Chiyoda Ward and Shinjuku Ward, which are mainly commercial and office buildings, with prosperous entertainment and dense population movement; suburban residential areas such as Setagaya Ward and Suginami Ward, which are mainly residential, with relatively well-developed living and service facilities (such as schools, banks, and hospitals); and there are waterfront areas such as Koto Ward and Shinagawa Ward, which are close to the rivers and the seashore, and emphasise the development of waterfront green spaces with beautiful landscapes. This diverse neighbourhood spatial coverage ensures the overall representativeness of the sample and helps to test the applicability and sensitivity of audit tool in different types of dense urban environments.

These parks scale range from 5 to 50 hectares. Additionally, they were categorised based on the Japanese area deprivation index [119]. Of these, there are nine parks located in high

socio-economic status areas, where the per capita income of residents is high and the level of public services is good, and green spaces are relatively well managed and maintained. The other 16 parks are in low socio-economic status, where communities face socio-economic inequality, lack of resources, and parks may have aging and under-maintained facilities.

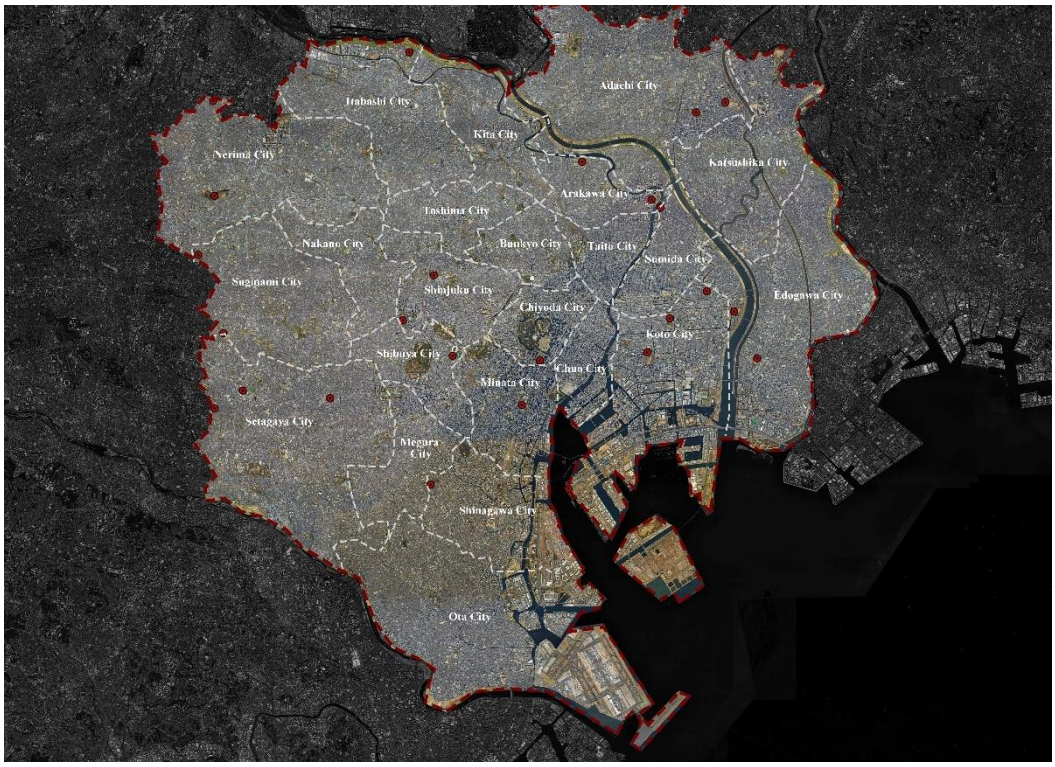

Figure 4.3. Geographical distribution of the 25 eligible parks

(Source: Google Earth, modified by the author)

Table 4.2. Summary of the 25 eligible parks

Park name	Address	Scale[1]	Area[2]	Population[3]	Population density[4]	ADI
Shioiri Park	13-1, Minami Senju 8-chome, Arakawa-ku, Tokyo 116-0003, Japan	L (12.9 ha)	10.16	217859	21442.81	5.47
Shinjuku Central Park	11-1, Nishi-Shinjuku 2-chome, Shinjuku-ku, Tokyo 160-0023, Japan	M (8.8 ha)	18.22	351085	19269.21	4.23

Sarue Park	13-7, Mouri 2-chome, Koto-ku, Tokyo 135-0001, Japan	L (14.5 ha)	43.01	276419	6426.85	4.65
Hanegi Park	38-52, Daita 4-chome, Setagaya-ku, Tokyo 155-0033, Japan	M (8.1 ha)	58.05	936846	16138.60	4.46
Kiba Park	4-6-1 Hirano, Koto-ku, Tokyo 135-0023, Japan	L (23.8 ha)	43.01	530561	12335.76	3.90
Kameido Central Park	9-37-28, Kameido, Koto-ku, Tokyo 136-0071, Japan	L (10.3 ha)	43.01	530561	12335.76	5.24
Hibiya Park	1 Hibiya Park, Chiyoda-ku, Tokyo 100-0012, Japan	L (16.1 ha)	11.66	67549	5793.22	0.00
Prince Shiba Park	10-17, Shiba-Koen 4-chome, Minato-ku, Tokyo 105-0011, Japan	L (12.2 ha)	20.37	262208	12872.26	3.66
Meiji Park	Kasumigaoka-cho, Shinjuku-ku, Tokyo 160-0013, etc.	M (6.1 ha)	18.22	351085	19269.21	5.38
Ukita Park	4-161, Ukida-cho, Edogawa-ku, Tokyo 134-0081, Japan	M (5.9 ha)	49.9	689059	13808.80	5.98
Rinshinomori Park	2-6-11, Oyamadai, Shinagawa-ku, Tokyo 142-0061, Japan	L (12 ha)	22.84	419155	18351.80	4.98
Higashi-Shirahige Park	2-2, Tsutsumidori, Sumida-ku, Tokyo 131-0034, Japan	L (10.3 ha)	13.77	276419	20074.00	8.48
Ogunohara Park	7-1 Higashi-Oku, Arakawa-ku, Tokyo 116-0012, Japan	M (6.2 ha)	10.16	217859	21442.81	5.63
Higashi-Ayase Park	3-4, Higashi-Ayase, Adachi-ku, Tokyo 120-0004, Japan	L (15.8 ha)	53.25	693330	13020.28	5.55

Toyama Park	2-7, Toyama, Shinjuku-ku, Tokyo 162-0052, Japan	L (18.6 ha)	18.22	351085	19269.21	7.74
Shakujii Park	Shakujiidai 1 and 2, Shakujiimachi 5, Nerima-ku, Tokyo 177-0045, Japan	L (22.6ha)	48.08	750631	15612.13	5.42
Ojima Komatsugawa Park	9-8 Oshima, Koto-ku, Tokyo 136-0072, Japan	L (24.9 ha)	43.01	530561	12335.76	6.07
Shiokaze Park	1-2, Higashiyashio, Shinagawa-ku, Tokyo 135-0092, Japan	L (15.4 ha)	22.84	419155	18351.80	5.22
Nakagawa Park	5-1 Nakagawa, Adachi-ku, Tokyo 120-0002, Japan	L (12 ha)	53.25	693330	13020.28	5.57
Zenpukuji Park	Zempukuji 2 and 3, Suginami-ku, Tokyo 167-0041	M (8 ha)	34.06	587185	17239.72	4.49
Soshigaya Park	3-22-19 Kamisoshigaya, Setagaya-ku, Tokyo 157-0065, Japan	M (9.4 ha)	58.05	936846	16138.60	4.62
Takaido Park	2 Kugayama, Suginami-ku, Tokyo 168-0082, Japan	M (8.1 ha)	34.06	587185	17239.72	4.86
Roka Koshun-en Gardens	1 Kasuya, Setagaya-ku, Tokyo 157-0063, Japan	M (8ha)	58.05	936846	16138.60	4.56
Oizumi-Chuo Park	9-4-3, Oizumigakuen-cho, Nerima-ku, Tokyo 178-0016, Japan	L (10.3ha)	48.08	750631	15612.13	0.00
Ukima Park	2-15-1, Funado, Itabashi-ku, Tokyo 174-0041	L (11 ha)	32.22	581773	18056.27	5.55

Note. Scale*:S:0-4 ha, M:4-10ha, L:10-50 ha, XL: over 50 ha.

Data source:

1. Area (square kilometres)：Statistics of Tokyo, 2023. くらしと統計

2023.https://www.toukei.metro.tokyo.lg.jp/kurasi/2023/ku23-23.htm;

2. Population: Statistics of Tokyo, 2023. くらしと統計

2023.https://www.toukei.metro.tokyo.lg.jp/kurasi/2023/ku23-23.htm;

3. Population density: Population/Area (square kilometres).

In conclusion, the selection of study cases for the reliability and validity validation of audit tool followed strict criteria and procedures to ensure the scientific and representative character of the sample. By targeting medium- to large-sized free and open urban parks in a densely populated area of Tokyo, and considering spatial distribution, scale differences, facility conditions, and socio-economic conditions, this study lays a strong basis for subsequent reliability and validity testing of the audit tool. In the future, as audit tool is applied in different urban environments, this sample selection framework can provide a reference path and experience for similar studies.

4.2.2 Auditor training

After identifying the 25 park cases, the next step is to conduct systematic training for auditors who conduct on-site audits of parks to ensure consistency and objectivity in the data collection process. Two auditors with backgrounds in urban design were recruited and received two days of intensive training. The training was divided into two phases: classroom and practical training, with the aim of providing auditors with a comprehensive understanding of the components of the audit tool, the assessment criteria for each item, and to achieve a high level of consistency with the trainer. The process of auditor training is summarised in Figure 4.4.

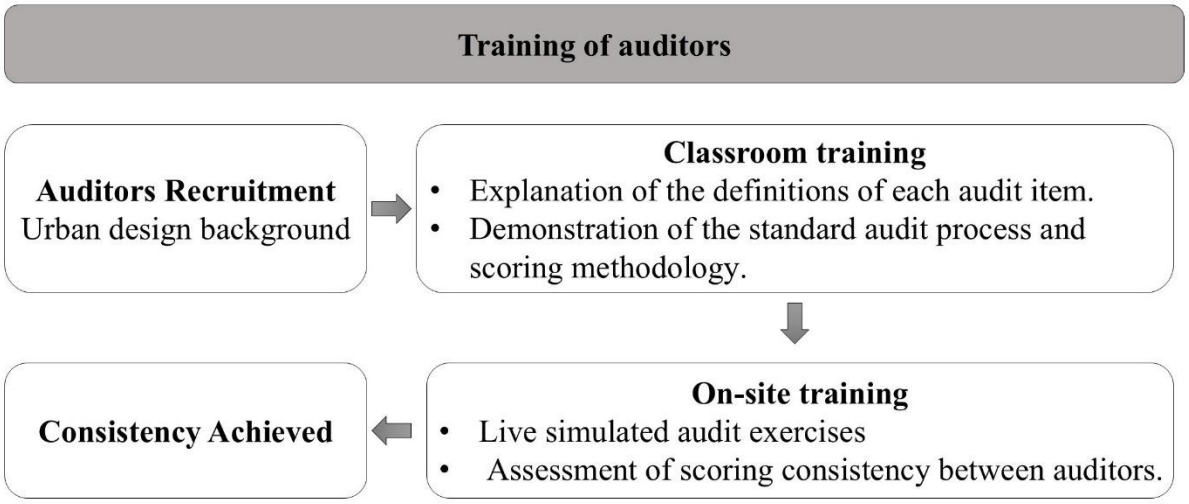

Figure 4.4. The process of auditor training

The first day of the training consisted of classroom training. The classroom training included an explanation of the structure of the audit tool with definitions of each audit item and a demonstration of the standard audit process and scoring methodology. First, audit tool framework including five dimensions, 24 environmental criteria, and their breakdown into 74 items. Then, through textual explanations, example pictures and discussions, the definitions of each dimension and item, the criteria for determining environmental features, and the scoring rules were explained in detail. Additionally, the training highlighted the issue of subjective bias that needs to be considered during the audit process and required auditors to make scoring judgments strictly based on the standardised instructions.

After completing the classroom training, both auditors proceeded to the on-site training stage. The on-site training consisted of on-site audit exercise and an assessment of inter-auditor scoring consistency. Two parks that were not included in the final validation sample were selected as practice sites for the on-site training. Two auditors were guided by a trainer with audit tool paper audit forms to perform on-site audit. The auditors were required to independently fill in the observation results of each audit item. The trainer assesses the consistency of auditors and compared them with the gold-standard responses from the trainer, which can explain, justify, and correct misunderstandings or inaccuracies in item scoring.

This hands-on practice ensured that the two auditors were able to achieve a high degree of consistency in the scoring of most items before the start of formal data collection. Through the training, the auditors were able to master the determination criteria for each audit item and the on-site operation process, minimising subjective bias and improving the reliability of the data.

4.2.3 On-site audit and data collection

After the auditors completed their training, a formal on-site audit to assess the reliability and validity of audit tool was conducted in February 2024. Two trained auditors travelled with the trainer to 25 target parks in Tokyo. Auditors and trainers entered each park simultaneously, holding paper copies of the audit tool and following a uniform process of evaluating the environmental criteria of the target parks with reference to park maps provided by Google Earth, information on the official park websites (e.g., facilities layout, opening hours, and accessibility), and other supporting information. Specific steps include: 1) recording basic information, such as park name, date, weather, audit start time; 2) evaluating specific items, such as entrances and exits, green spaces, paths, activity venues, facility accessibility, safety; 3) recording the audit end time after completing the scoring of all the items; and 4) taking on-site photographs related to the key audit items to assist in the follow-up data analysis and discussion. Figure 4.5 shows site photographs related to key audit items.

Auditors make independent assessments on each item without discussion with each other to ensure independence of the data. Auditors are required to record their observations of each item according to standardised definitions and score the observations on the paper version of audit tool. Answers are based on the type of item response (a dichotomous or 3-point scale). For example, “Are there any guidance or warning signs for fitness area users?” is a dichotomous judgement (No/Yes), while “Are the fitness areas in good condition? (Consider the cleanliness, management and safety)” uses a 3-point scale of quality (None/Some/A lot). After data collection, all paper-based records were uniformly entered into an electronic database, an Excel sheet. The audits were conducted during sunny, rain-free daytime hours to minimise external environmental disturbances and ensure data consistency.

(a) Entrance point (b) Path

(c) Playground (d) Warning sign

Figure 4.5. Status of audit items of testing parks

4.2.4 Statistical analysis

This subsection describes the statistical methods used to assess the reliability and validity of audit tool. Cohen's kappa coefficient and percent agreement were used to assess the reliability of the audit tool. The agreement rate with the gold standard (assess by trainer) was used to assess the validity of audit tool. All statistical analyses were processed and calculated using IBM SPSS Statistics 29 software.

Inter-rater reliability. The reliability of audit tool was assessed by measuring the level of agreement between two auditors in scoring audit items for each park. In this study, two complementary statistical methods were used to assess inter-rater reliability: 1) Cohen's kappa and 2) percent agreement. Kappa coefficient is the most used statistical measure of scoring agreement between two raters, and it can eliminate the possibility of consistency occurring by chance [120]. Kappa values range from 1 to -1, with closer to 1 indicating a higher level of agreement and less than 0 indicating a lower level of agreement. According to Landis and Koch [121], kappa values are classified as follows: kappa $\geq$ 0.81 indicates an almost perfect agreement; 0.61 $\leq$ kappa < 0.80 indicates substantial agreement; 0.41 $\leq$ kappa < 0.60 indicates moderate agreement; 0.21 $\leq$ kappa < 0.40 indicates fair agreement; 0.00 $\leq$ kappa < 0.20 indicates poor agreement; and kappa < 0.00 indicates very poor agreement. Additionally, percent agreement indicates the proportion of two auditors who give the same rating on the same audit item. Items are considered to have reached an acceptable level of agreement if they

percent agreement over 70% [64].

Validity Assessment. The validity of audit tool was measured by assessing the level of agreement between the auditors' scores and the gold standard. As the expert trainers has extensive experience in park auditing and is familiar with the definitions and assessment standards for each of audit tool items, they ratings are accurate and indicative. Therefore, the ratings of the expert trainers were considered the "gold standard" and were used as the basis of reference for the auditors' ratings to assess the validity of the audit tool. For example, if the auditor's rating of an item agrees with the expert's rating, it is considered as one valid match. The validity ratio for that item is derived by calculating the percentage of all valid matches in the total rating. This approach draws on [61] in the development of an environmental audit tool for parks.

4.3 Results of audit tool testing

This subsection presents the key findings of the testing of audit tool. Cohen's kappa coefficient and percent agreement were used to assess the reliability of the audit tool. The agreement rate with the gold standard was used to assess the validity of audit tool. This section presents two key results: 1) the reliability of the audit tool at the dimension level and at the item level; and 2) the validity of the audit tool at the dimension level and at the item level.

4.3.1 Reliability of audit tool

Reliability of items. The audit tool items were found to have high reliability based on the Cohen's kappa coefficient and percent agreement statistics. Dense urban park audit tool consisted of 74 items, of which 29 items lacked sufficient variability in scoring to calculate a kappa value due to identical scoring. Although this lack of variation limits statistical calculations, it reflects the fact that these items are well-defined and easy to observe and judge.

Among the remaining 45 items, there were 40 items (accounting for 88.9%) with kappa coefficients higher than 0.4, reaching the level of 'moderate agreement' or above. Only five items were in the 'poor to fair agreement' range with a kappa < 0.4. Additionally, the percent agreement was calculated for all of 74 items. Of these, three items had percent agreement below the pre-set threshold of 70 %. The remaining 95.9 % of the items had an inter-rater percent agreement of more than 70%, confirming that most of the items had a high level of scoring agreement. Table 4.3 demonstrates the reliability at the item level. In summary, the audit tool items showed a high level of reliability.

Table 4.3. Reliability at the item level.

Criteria	Items	Kappa	Percent agreement
Entrance points and signage	1.How many entrance points are there to access the park smoothly?	N/A	100.0%
	2. Are there any signs showing the location or directions to the park?	1.00	100.0%
	3. Are there any park information at the entrance points?	N/A	100.0%
	4. Are the entrance points attractive for residents?	0.42	76.0%
Traffic safety	5. Are there any crosswalks on the road to access the park?	N/A	100.0%
	6. Are there any traffic lights on the crosswalk?	1.00	100.0%
	7. Are there any signs of speed limit on the roads to access the park?	N/A	100.0%
	8. Are the traffic situation around the park generally safe for residents?	0.31	68.0%
Roads bordering the park	9. Are there sidewalks/bike lanes on the roads bordering the park?	N/A	100.0%
	10. Are the width of the sidewalk/bike lane suitable for walking/cycling?	N/A	96.0%
	11. Are there any obstacles on the sidewalk/bike lane that prevent you from moving on? *	N/A	92.0%
Public transport station	12. Are there any public transport stations close to the park?	1.00	100.0%
	13. How long is the walking or cycling time from the public transport station to the nearest park entrance point (min)? *	N/A	100.0%
Parking lot	14. Are there any parking lots?	1.00	100.0%
	15. Are there any bicycle racks?	1.00	100.0%
	16. Is the parking free?	1.00	100.0%
	17. Is it convenient to parking?	0.06	61.9%
Sport court	18. What sports courts are in the park?	1.00	100.0%
	19. Are the sports court usable?	N/A	100.0%
	20. Are the sports court free to use?	1.00	100.0%
	21. Are there any guidance or warning signs for sports court users?	0.64	95.2%
	22. Are there any benches to rest on?	1.00	100.0%
	23. Are there any shade areas or shelter in the sport court?	1.00	100.0%
	24. Are the sports court fenced?	1.00	100.0%
	25. Are the sports court in good condition?	0.66	85.7%
Playground	26. Are there any playgrounds in the park? (If not, please skip to 31)	1.00	100.0%

	27. Are the playgrounds usable? (If people are using it, it is usable. If no one is using it, consider whether it is forbidden, or abandoned.)	1.00	100.0%
	28. How many types of playgrounds equipment are present? (e.g., swings, seesaws, slides, trampolines, carousels, rock climbing, etc.)	0.75	91.3%
	29. Are there any guidance or warning signs for playground users?	1.00	100.0%
	30. Are the playgrounds in good condition? (Consider the cleanliness, management and safety)	N/A	87.5%
	31. Are there any tracks specifically for running? (If not, please skip to 34)	1.00	100.0%
Running track	32. Are there any obstacles on the running tracks that prevent you from moving on? *	N/A	90.0%
	33. Are the running tracks in good condition? (Consider the cleanliness, surface and management)	N/A	70.0%
	34. Are there any fitness areas in the park? (If not, please skip to 37)	1.00	100.0%
Fitness area	35. Are there any guidance or warning signs for fitness area users?	N/A	100.0%
	36. Are the fitness areas in good condition? (Consider the cleanliness, management and safety)	N/A	86.7%
	37. Are there any public /green spaces in the park? (It is a space where people can freely access and conduct activities.) (If not, please skip to 41)	N/A	100.0%
Public /Green space	38. Are the surface of the public /green spaces flat?	0.34	80.0%
	39. Are there any guidance or warning signs for public /green spaces users?	N/A	100.0%
	40. Are the public/green spaces in good condition? (Consider the cleanliness, safety, and maintenance)	0.65	96.0%
	41. Are there any walking paths in the park?	N/A	100.0%
	42. Are the paths with the appropriate width for walking?	N/A	100.0%
Path	43. Are there any obstacles on the path? *	N/A	100.0%
	44. Are the paths sloping? *	0.64	80.0%
	45. Are the paths in good condition?	0.65	96.0%
	46. Are there any public toilets in the park?	N/A	100.0%
Public toilet	47. Are there any amenities offered in the toilets?	0.63	92.0%
	48. Are the public toilets in good condition?	0.23	64.00%
	49. Are there any shelters and pavilions in the park?	1.00	100.0%
Shelter and pavilion	50. Are there any benches to rest under the shelters and pavilions?	N/A	100.0%
	51. Are the shelters and pavilions in good condition?	0.63	91.7%
	52. Are there any drinking fountains in the park?	N/A	100.0%

Drinking fountain	53. Are the drinking fountains usable?	N/A	100.0%
Bench	54. Are there any benches to rest in the park?	N/A	100.0%
	55. Are there any tree shades or coverage on the benches?	0.60	80.0%
	56. Are there any pleasant views while resting on the benches?	0.51	76.0%
	57. Are the benches in good condition?	0.06	88.0%
Picnic table	58. Are there any picnic tables in the park?	1.00	100.0%
	59. Are there any tree shades or coverage on the picnic table?	0.53	76.2%
	60. Are the picnic tables in good condition?	0.78	95.2%
Trash can	61. Are there any trash cans in the park?	1.00	100.0%
	62. Are the trash cans easy to find in the park?	0.52	73.9%
	63. Are the trash cans in good condition?	0.68	87.0%
Vegetation and landscape	64. How many species of vegetation can you identify in the park?	0.65	96.0%
	65. Has any vegetation and landscape in the park been uprooted or damaged? *	N/A	100.0%
	66. Are the vegetation and landscape in good condition?	N/A	92.0%
Graffiti	67. Are there any graffiti in the park? *	N/A	100.0%
Litter	68. Are there any litter in the park? *	0.70	92.0%
Lighting	69. Are there adequate lighting in the park?	0.58	84.0%
Surveillance equipment	70. Is there surveillance equipment in the park?	1.00	100.0%
Emergency device	71. Are there any emergency devices in the park?	1.00	100.0%
	72. Are the locations of any emergency equipment marked on the park map?	1.00	100.0%
Warning sign	73. Are there any warning signs in the park?	N/A	100.0%
	74. Are these warning signs clear?	N/A	96.0%

NA: not available, if item responses lacked sufficient variability.

Reliability of dimensions. The results based on Cohen's kappa coefficient and percent consistency show a good reliability performance on the dimensional level of audit tool. As shown in Table 4.4, the overall Cohen's kappa coefficient is 0.76 and the overall percent agreement is 94.54%, indicating good reliability. Of the five dimensions, the safety dimension had the highest kappa value of 0.89, showing near perfect agreement. Comparatively, facilities and amenities had the lowest kappa of 0.63, which is slightly lower but still in the 'substantial agreement' range. Nonetheless, the kappa coefficients for all dimensions are above 0.60, indicating stable and reliable agreement across the audit tool dimensions. Additionally, the percent agreement for all dimensions exceeded 91.2%, with an overall average of 94.5%, further validating the good reliability of audit tool.

Table 4.4. Reliability at the dimensional level.

Dimensions	Item (n)	N/A	Cohen's kappa			Percent agreement		
			Average kappa	N ≥ 0.40 kappa	% ≥ 0.40 kappa	Average agreement	N ≥70% agreement	% ≥70% agreement
Park surroundings and accessibility	17	8	0.75	7	77.80%	93.80%	15	88.24%
Activity areas	23	8	0.87	15	100.00%	94.90%	23	100.00%
Facilities and amenities	23	8	0.63	13	86.67%	91.30%	22	95.65%
Aesthetics	5	3	0.68	2	100.00%	96.00%	5	100.00%
Safety	6	2	0.89	4	100.00%	96.70%	6	100.00%
Total	74	29	0.76	41	91.11%	94.54%	71	95.95%

Note. NA: not available, if item responses lacked sufficient variability.

4.3.2 Validity of audit tool

Validity of items. Item validity was measured by the agreement between the auditor's ratings of each item and the gold standard ratings. Table 4.5 shows the validity results of the audit tool items. According to the results, audit tool has good validity at the item level. Of the total 74 items, 53 items achieved 100% agreement with the gold standard. There were 7 items that achieved 90 % to 99 % agreement with the gold standard and 7 items that achieved 80 % to 89 % agreement with the gold standard. Six items were aligned with the gold standard at 70% to 79%, while only one item was aligned with the gold standard at 60% to 69%. The results of audit tool, with 81% of items having more than 90% agreement with the gold standard, demonstrate a high level of agreement between the auditors and the expert trainers, as well as a good level of validity of the audit tool items.

Table 4.5. Validity at the item level.

Criteria	Items	Validity (gold standard)
	1.How many entrance points are there to access the park smoothly?	100.0%

Entrance points and signage	2. Are there any signs showing the location or directions to the park?	100.0%
	3. Are there any park information at the entrance points?	100.0%
	4. Are the entrance points attractive for residents?	71.4%
Traffic safety	5. Are there any crosswalks on the road to access the park?	100.0%
	6. Are there any traffic lights on the crosswalk?	100.0%
	7. Are there any signs of speed limit on the roads to access the park?	100.0%
	8. Are the traffic situation around the park generally safe for residents?	71.4%
Roads bordering the park	9. Are there sidewalks/bike lanes on the roads bordering the park?	100.0%
	10. Are the width of the sidewalk/bike lane suitable for walking/cycling?	100.0%
	11. Are there any obstacles on the sidewalk/bike lane that prevent you from moving on? *	100.0%
Public transport station	12. Are there any public transport stations close to the park?	100.0%
	13. How long is the walking or cycling time from the public transport station to the nearest park entrance point (min)? *	100.0%
Parking lot	14. Are there any parking lots?	100.0%
	15. Are there any bicycle racks?	100.0%
	16. Is the parking free?	100.0%
	17. Is it convenient to parking? (Consider the entrance and exit signs, and parking management)	72.20%
Sport court	18. What sports courts are in the park?	100.0%
	19. Are the sports court usable?	100.0%
	20. Are the sports court free to use?	100.0%
	21. Are there any guidance or warning signs for sports court users?	100.0%
	22. Are there any benches to rest on?	100.0%
	23. Are there any shade areas or shelter in the sport court?	100.0%
	24. Are the sports court fenced?	100.0%
	25. Are the sports court in good condition?	88.20%
Playground	26. Are there any playgrounds in the park? (If not, please skip to 31)	100.0%
	27. Are the playgrounds usable? (If people are using it, it is usable. If no one is using it, consider whether it is forbidden, or abandoned.)	100.0%
	28. How many types of playgrounds equipment are present? (e.g., swings, seesaws, slides, trampolines, carousels, rock climbing, etc.)	85.00%

	29. Are there any guidance or warning signs for playground users?	100.0%
	30. Are the playgrounds in good condition? (Consider the cleanliness, management and safety)	90.0%
	31. Are there any tracks specifically for running? (If not, please skip to 34)	100.0%
Running track	32. Are there any obstacles on the running tracks that prevent you from moving on? *	100.0%
	33. Are the running tracks in good condition? (Consider the cleanliness, surface and management)	100.0%
	34. Are there any fitness areas in the park? (If not, please skip to 37)	100.0%
Fitness area	35. Are there any guidance or warning signs for fitness area users?	100.0%
	36. Are the fitness areas in good condition? (Consider the cleanliness, management and safety)	90.9%
	37. Are there any public /green spaces in the park? (It is a space where people can freely access and conduct activities.) (If not, please skip to 41)	100.0%
Public /Green space	38. Are the surface of the public /green spaces flat?	76.2%
	39. Are there any guidance or warning signs for public /green spaces users?	100.0%
	40. Are the public/green spaces in good condition? (Consider the cleanliness, safety, and maintenance)	90.5%
	41. Are there any walking paths in the park?	100.0%
	42. Are the paths with the appropriate width for walking?	100.0%
Path	43. Are there any obstacles on the path? *	100.0%
	44. Are the paths sloping? *	90.5%
	45. Are the paths in good condition?	95.2%
	46. Are there any public toilets in the park?	100.0%
Public toilet	47. Are there any amenities offered in the toilets?	85.7%
	48. Are the public toilets in good condition?	66.7%
	49. Are there any shelters and pavilions in the park?	100.0%
Shelter and pavilion	50. Are there any benches to rest under the shelters and pavilions?	100.0%
	51. Are the shelters and pavilions in good condition?	100.0%
Drinking fountain	52. Are there any drinking fountains in the park?	100.0%
	53. Are the drinking fountains usable?	100.0%
	54. Are there any benches to rest in the park?	100.0%
Bench	55. Are there any tree shades or coverage on the benches?	71.4%
	56. Are there any pleasant views while resting on the benches?	100.0%
	57. Are the benches in good condition?	85.7%
Picnic table	58. Are there any picnic tables in the park?	100.0%

Trash can	59. Are there any tree shades or coverage on the picnic table?	88.2%
	60. Are the picnic tables in good condition?	94.1%
	61. Are there any trash cans in the park?	100.0%
	62. Are the trash cans easy to find in the park?	89.5%
	63. Are the trash cans in good condition?	84.2%
Vegetation and landscape	64. How many species of vegetation can you identify in the park?	100.0%
	65. Has any vegetation and landscape in the park been uprooted or damaged? *	100.0%
	66. Are the vegetation and landscape in good condition?	90.5%
Graffiti	67. Are there any graffiti in the park? *	100.0%
Litter	68. Are there any litter in the park? *	100.0%
Lighting	69. Are there adequate lighting in the park?	71.4%
Surveillance equipment	70. Is there surveillance equipment in the park?	100.0%
Emergency device	71. Are there any emergency devices in the park?	100.0%
	72. Are the locations of any emergency equipment marked on the park map?	100.0%
Warning sign	73. Are there any warning signs in the park?	100.0%
	74. Are these warning signs clear?	100.0%

Validity of dimensions. Dimension-level validity was calculated by summarising the level of agreement between auditor ratings of items and gold standard ratings under each dimension. Table 4.6 demonstrates the dimension level validity. The results indicated that the overall validity of the audit tool dimensions was 87.5%, meaning that the audit tool dimensions overall reached 87.5% agreement with the gold standard. Additionally, all five dimensions achieved more than 80% agreement with the gold standard ratings. Among them, the Aesthetics dimension had the highest agreement with the gold standard at 95.24%, while Facilities and amenities had the lowest agreement with the gold standard at 83.33%. The second highest level of consistency with the gold standard is in the Activity areas at 87.50 per cent, followed in descending order by Safety and Park surroundings and accessibility. With the exception of the Facilities and amenities dimension, all items in the other four dimensions had an agreement with the gold standard of more than 70 %. This demonstrates that audit tool can effectively reflect the characteristics of park environments and is a strong tool for park audits.

Table 4.6. Validity at the dimensional level.

Dimensions	**Items (n)**	**Validity**		
		Average agreement	**N ≥70% agreement**	**% ≥70% agreement**
Park surroundings and	17	85.70%	17	100.00%

accessibility				
Activity areas	23	87.50%	23	100.00%
Facilities and amenities	23	83.33%	21	91.30%
Aesthetics	5	95.24%	5	100.00%
Safety	6	85.71%	6	100.00%
Total	74	87.50%	72	97.30%

Overall, the results of the reliability and validity tests of audit tool indicate that it has demonstrated good measurement reliability and scientific validity in assessing the attributes of park-supported physical activity in dense urban environments. Cohen's kappa values for all five dimensions were at the “substantial agreement” or “near perfect” level, with an average of more than 94.5 % agreement on auditors’ scores and 87.5 % agreement with the experts’ gold standard. These results verify the reliability and validity of audit tool as a scientific and systematic auditing tool, and provide a reliable measurement basis and decision-making support for the improvement of park environment and the formulation of urban health intervention strategies in the context of dense urban areas.

4.4 Discussions of audit tool testing

4.4.1 The causes of low reliability and validity

The results of this study indicate that the audit tool exhibits good to excellent audit reliability and validity in dense urban environments, particularly in achieving high levels of consistency at the overall level of the dimensions and for most objective items. However, it was also found in this field test of the audit tool that some perceptual items that rely on subjective judgement, such as perceptions of traffic safety, and conditions of benches and public toilets, showed slightly lower inter-rater agreement compared to the objective dichotomous items.

These findings are consistent with the established literature, which has pointed out that the scoring results of perceptual items are susceptible to external factors such as the auditors' personal judgement, the weather conditions on the day and the timing of the audit [62, 64]. A few specific factors influencing this are summarised below:

1) Variability in subjective judgements. Perceptual items usually do not have clear, quantitative standards of judgement and rely more on the auditors' personal experience, and risk sensitivity, even though the auditors have been through training [18]. For example, in the case of ‘perceptions of traffic safety’, one auditor may perceive a park close to a main road as having a higher traffic risk, while another may think that accessibility can be improved.

2) Differences in audit times affect perceptual items. Ratings of perceptual items may vary with different times of the day. For example, auditing during peak traffic times may result in high auditor perceptions of crowding or security; while early mornings or off-peak times, when the environment is relatively quiet, may result in low ratings. This ‘time sensitivity’ increases the possibility of fluctuating ratings. Although temporal differences may affect the auditors' own perceptions at different times of the day, in this study it was emphasised that the auditors carried out their audits at the same time.

3) Interference of weather and lighting conditions. Weather conditions directly affect the auditor's observation experience. Cloudy, hazy, sunny or rainy days may mask or magnify certain environmental features, such as road visibility, state of use of benches, tidiness of green spaces, etc. affecting subjective judgement of perceptual items.

4) Differences in experience between auditors. Even if they have received the same training, differences in auditors' experience in previous project participation, urban planning or environmental assessment may affect their interpretation of the same situation [18].

4.4.2 Suggestions for improving reliability and validity

To mitigate these problems and to further improve the reliability and validity of audit tool, especially in the application of perceptual items, future practice and research should focus on the following points. First, systematic and standardised auditor training is important. Not only does training help auditors familiarise themselves with the structure, scoring criteria, and on-site operational procedures of audit tool, but it also significantly improves the consistent performance of perceptual items [72]. The training session in the present study demonstrated that systematic training plays an important role in improving the scoring agreement.

Second, it is recommended that auditors consult the official park website prior to the on-site audit to understand the configuration and daily use of the facilities [48]. This can improve the auditors' understanding of the park environment, and can be particularly positive in identifying facility items. However, it should be noted that the applicability of this strategy may be limited for smaller community parks or those that lack online information.

Thirdly, to increase the objectivity of scoring and reduce individual bias, this study recommends that at least two trained auditors conduct the audit independently, ultimately resulting in a consistent score through comparison and proofreading [50]. This method enhances the scientific validity and reliability of the scores, which is especially critical for items with a high influence of subjective factors.

Finally, considering the time and resources required for on-site audits, the possibility of transforming audit tool into an online remote assessment tool could be explored in the future. If an effective remote auditing version can be developed, audit tool is expected to be more widely used in resource-constrained areas or large-scale assessment projects, thus increasing its utility and potential for replication [87].

In conclusion, our audit tool has been validated initially for its reliability and validity as a tool applicable to environmental assessment in dense urban parks. However, to further enhance the performance of audit tool, especially in the assessment of perceptual items, future studies still need to continue to explore and improve the training system, scoring approach and remote application.

4.5 Summary

This chapter systematically describes dense urban park audit tool on-site audit process and the results of its reliability and validity analyses. Firstly, a representative sample of 25 medium to large urban parks in Tokyo, an ultra-dense urban environment, was selected. A series of stringent processes including auditor training (theoretical and practical training), on-site assessment and statistical analysis were then completed. Then the reliability and validity of audit tool were analysed. The results of the reliability and validity study of audit tool show that audit tool overall has good to excellent reliability and validity. Meanwhile, the items and dimensions with lower reliability and validity were identified through the analysis. It provides suggestions for reference for the improvement of future research, such as maximally controlling the variables affecting the reliability and validity by using systematic training and standardised operational procedures.

In conclusion, audit tool, as an observational assessment tool designed for dense urban park environments, has been empirically studied. It is verified that audit tool demonstrates a high level of reliability and validity in practical application.

Chapter 5 Adapting audit tool for remote audit

5.1 Introduction

5.1.1 Advantages and limitations of on-site audit tools

To effectively evaluate park features that support physical activity, researchers have developed various on-site audit tools, such as the Public Open Space Tool (POST) [91], the Community Park Audit Tool (CPAT) [122], and audiT tool for Activity-friendly Parks in denSe urban areas (TAPS) [39], which was developed in this study. These tools use systematic field observations to assess park attributes, including accessibility, facilities, and safety. They provide objective methods of measurement and support for decision-making in environmental assessment and urban health interventions.

With advances in technology and the increasing availability of data visualisation tools, urban environment research is gradually shifting towards more efficient and lower-cost methods of data collection. In traditional environment audits based on field visits, transport, funding, time, and human resources have often posed major barriers to large-scale, consistent, and fair data collection [123]. This has made it difficult to apply on-site audits in studies involving large samples or multiple locations [124]. Therefore, there is an urgent need to develop more efficient and reliable remote audit tools to improve the feasibility and scope of data collection.

5.1.2 Emergence and prospects of remote audit

In recent years, the growing availability of geographic information and satellite imagery platforms—such as Google Earth Pro—has enabled remote auditing as a new alternative to traditional on-site assessments [125]. Compared with conventional methods, remote audits offer significant time and cost savings. They also allow for the storage and re-examination of visual data, enhancing the transparency and verifiability of the auditing process [125, 126]. This approach helps overcome logistical constraints of time and location, while improving auditing efficiency and the potential for replication across different regions. Studies have shown that remote audits can demonstrate good reliability and validity in health and environmental research, and they have been widely applied to assess streets, neighbourhoods, and community environments [48, 127].

5.1.3 Special requirements of dense urban areas in Asia

Most existing remote audit tools have been designed for low-density urban areas, and

there has been limited systematic development or validation of such tools for assessing parks in dense urban areas in Asian [125]. Park usage patterns in dense urban areas of Asia also differ significantly from those in low-density cities in the West [58]. For example, Asian cities often feature a higher degree of spatial multifunctionality, more complex block structures, and a stronger culture of neighbourhood-based activities [128, 129]. Therefore, such studies are needed to account for the unique built environment forms and social norms that distinguish these dense urban areas from low-density contexts.

More importantly, existing research has indicated that the urban density gradient influences both park accessibility and the frequency of park use [32]. As a result, remote audit tools developed for low-density contexts may have limited applicability in dense urban areas. This underscores the need to develop context-specific tools tailored to the unique environmental and behavioural characteristics of dense urban areas, particularly in Asian, where existing tools may fail to capture local nuances effectively.

5.1.4 Aims and structure of remote audit tool

The aim of this chapter is to adapt dense urban park audit tool into a remote audit tool. In Chapter 3, dense urban park audit tool was developed as an on-site audit tool specifically designed to assess park attributes that support physical activity in dense urban environments. Chapter 4 described the systematic evaluation of the tool's reliability and validity in a dense urban district of Tokyo, Japan. The findings demonstrated that dense urban park audit tool possesses good reliability and validity, effectively capturing key environmental features that influence physical activity in parks in dense urban areas. Given the limitations of on-site audit in large-scale studies, this chapter focuses on the adapting dense urban park audit tool to a remote version.

This chapter provides a systematic introduction to the development and testing process of remote audit tool. The development process includes the item adaptation strategy, the selection of the platform to be used, and the design of the remote audit process. The testing phase presents the results of the reliability and validity test of remote audit tool in practical applications to verify its feasibility as a remote tool. The goal of this adaptation is not only technical but also methodological, expanding the utility of both dense urban park audit tool and remote audit tool in global urban health research contexts.

5.2 Methods

This section describes the methodology used to adapt and test remote audit tool for use in dense urban settings. The adaptation and validation of remote audit tool followed a structured and standardised process, ensuring methodological rigour and facilitating comparison with the original on-site version of dense urban park audit tool. The adaptation of remote audit tool includes the following steps: (1) the selection of study cases; (2) the selection of a remote audit

platform; (3) the adaptation process of the remote audit tool. The testing steps of remote audit tool include: (1) auditor training; (2) reliability and validity testing, and (3) statistical analysis. The aim of this standardised methodological process is to validate the reliability and effectiveness of remote audit tool as a remote assessment tool for dense urban environments.

5.2.1 Study sample

This subsection describes the cases selection process of remote audit tool. To ensure methodological rigour and allow for direct comparison between the reliability and validity of remote audit tool and dense urban park audit tool, the case selection strategy used in this subsection is consistent with that of dense urban park audit tool [39].

Urban parks in Tokyo, Japan, were selected as the study sample for the remote audit tool. Tokyo is one of the most densely populated cities in the world, with an average population density of 6,410 people per square kilometre [130], and it exhibits typical features of dense urban environments, such as intense urbanisation and limited land availability. The park samples were drawn from the “Tokyo Metropolitan Park Guide” published by the Tokyo Metropolitan Government, which contains detailed information on 82 urban parks, including each park’s location, area, transportation accessibility, opening hours, and distinctive facilities [117].

In line with dense urban park audit tool, the selection of the sample of remote audit tool was considered on the basis of the following four factors: 1) spatial distribution: to ensure that the sample is spatially representative, the parks were selected to cover all 23 special wards and 26 municipalities in the Tokyo metropolitan area; 2) diversity of socio-economic status of the area: the areal deprivation index [119], which was developed based on Japanese census data, was used to ensure that the parks selected were located in neighbourhoods with different socio-economic status; 3) diversity of featured facilities: priority was given to the inclusion of parks with featured elements such as different types of fitness facilities, children's play facilities, green spaces, to enhance the appropriateness of the remote audit tool on the facilities dimension; 4) park size distribution: to ensure the observability and completeness of information during the audit process, the study focused on selecting medium to large-sized parks (5 to 50 hectares). Parks that are too small tend to lack sufficient auditable facilities and spatial dimensions, while super-large parks are rare in dense urban areas and suffer from the complexity of management authority and access conditions; 5) parks located in low-density suburban areas and parks requiring paid entrance were excluded to ensure that the target environment of the remote audit tool was consistent with the actual application context. Ultimately, a total of 53 eligible medium to large urban parks were included in the remote audit sample. Figure 5.1 shows the geographical locations of the 53 parks.

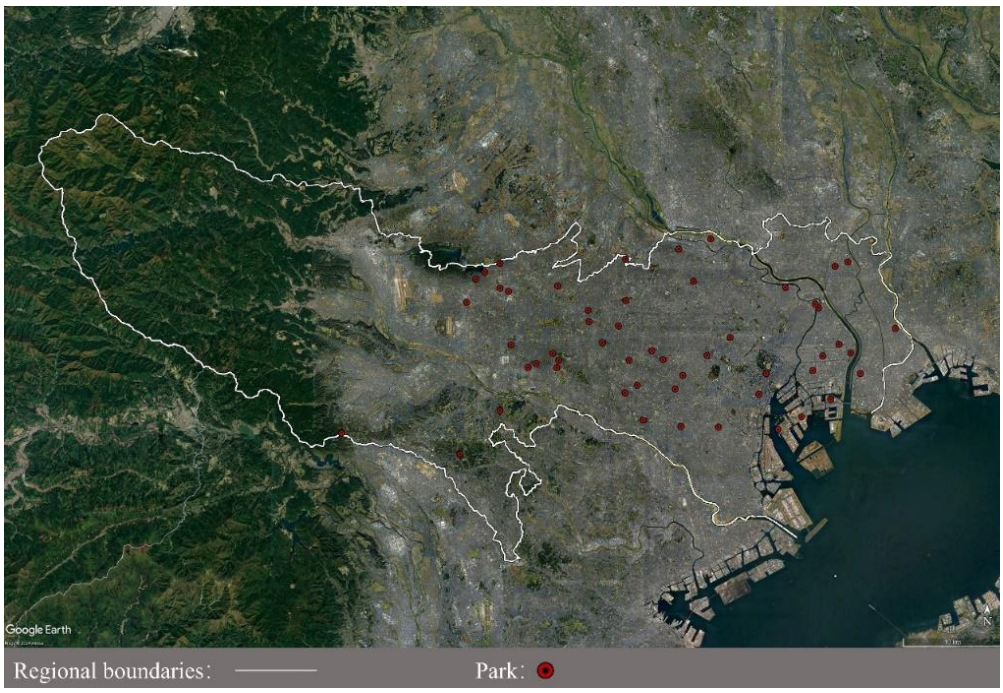

Figure 5.1. The geographical locations of parks in Tokyo

(Source: Google Earth, modified by the author)

5.2.2 Data source

This subsection details the remote audit platform and data source used in this study. The application version of Google Earth, Google Earth Pro, was used as the data source for remote audit, as shown in Figure 5.2. Google Earth Pro is a virtual earth tool based on Google Maps that provides free satellite imagery and street view [131].

Figure 5.2. Google Earth Home

Google Earth Pro is commonly used due to its powerful features and advantages. First, Google Earth Pro has the function of multi-view observation [132]. It allows the user to examine the image from a top-down perspective, as shown in Figure 5.3, and provides a view of smaller environmental features through its Street View feature, as shown in Figure 5.4. Additionally, Google Earth Pro has been widely used in constructed environment and health studies to assess the relationship between urban environmental characteristics and health behaviours, and the ethical aspects of its landscape visualisation have been discussed [131, 133]. Finally, one of the strong advantages of Google Earth Pro is the ability to store and revisit data. It supports the storage of image data for easy validation and re-examination in subsequent audit processes [131].

Figure 5.3. Google Earth Pro: top-down perspective

Figure 5.4. Google Street View: “eye-level” view

5.2.3 Adaptation process

This subsection describes the procedure of adapting dense urban park audit tool to a remote audit version, for use in assessing park environments supporting physical activity in dense urban areas. The adaptation process involved reassessment of item visibility, screening, reconstruction of items and modification of scoring scales.

Overview and adaptation background of dense urban park audit tool. Dense urban park audit tool was built by consensus by multiple urban planning and health behaviour experts as an on-site audit tool to assess the environmental attributes that contribute to the promotion of physical activity in parks in dense urban areas [39]. Dense urban park audit tool is structured with five dimensions (park surroundings and accessibility, activity areas, facilities and amenities, aesthetics, and safety), 24 criteria for evaluation, and 74 specific audit items. In reliability and validity tests, audit tool demonstrated good measurement performance, with 91.1% of the audit items having moderate or above reliability and overall validity of 87.5% [39]. However, the application of audit tool relies on direct observation by auditors in the field, which is demanding on time, manpower and funds, and is difficult to be applied to studies with large samples or across regions. Therefore, to improve the width of application and audit efficiency of audit tool, it is necessary to adapt it to a remote auditing version that can be operated based on satellite imagery and street view data.

Visibility assessment and item screening. For ensuring that the remote audit tool was operational in Google Earth Pro, an item-by-item visibility assessment of dense urban park audit tool 74 items was conducted. A representative sample of 4 urban parks (Shinjuku Central Park, Hanegi Park, Shioiri Park, and Sarue Park) was selected for visibility testing in both satellite imagery and street view perspectives in Google Earth Pro. Two main auditors used

Google Earth Pro to independently review each item and record its visibility in remote imagery. During the assessment process, auditors were asked to add explanatory notes to the detectability assessment for each item, documenting the basis for the judgement.

After the two auditors had completed their assessments independently, discussions were held on the visibility of each item to determine which should be retained and which should be deleted. For items where there was disagreement, a third researcher with a professional background was invited to participate in the discussion until a consensus was reached. Ultimately, items that were difficult to observe in Google Earth Pro or for which scoring accuracy could not be guaranteed were removed or merged. For example, items such as “Are the drinking fountains usable?” and “Are the vegetation and landscape in good condition? (Consider the management, mow, and design)” were excluded due to the inability to accurately capture condition assessments through remote viewing and the inability of static images to capture changes in facility functionality over time. Table 5.1 shows the adaptation results for 74 items.

Table 5.1. The adaptation results

Adaptation of remote audit tool from dense urban park audit tool								
Dense urban park audit tool			**Shinjuku Central Park**	**Hanegi Park**	**Shioiri Park**	**Sarue Park**	**Note**	**Remote audit**
Domains	**Criteria**	**Items**						
Park surroundings and accessibility	Entrance points and signage	1. How many entrance points are there to access the park smoothly?	√	√	√	√	Detectable by the top-down satellite view.	√
		2. Are there any signs showing the location or directions to the park?	√	√	√	√	Detectable by sight level view.	√
		3. Are there any park information at the entrance points? (e.g., park name, maps, opening hours, rules and prohibitions)	√	√	√	√	Detectable by sight level view.	√
		4. Are the entrance points attractive for residents?	×	×	×	×	Perceptual item could not be accurately captured through remote viewing.	×
	Traffic safety	5. Are there any crosswalks on the road to access the park?	√	√	√	√	Detectable by the top-down satellite view.	√
		6. Are there any traffic lights on the crosswalk?	√	√	√	√	Detectable by sight level view.	√
		7. Are there any signs of speed limit on the roads to access the park?	√	√	√	√	Detectable by sight level view.	√
		8. Are the traffic situation around the park generally safe for residents?	×	×	×	×	Perceptual item could not be accurately captured through remote viewing.	×
		9. Are there sidewalks/bike lanes on the roads bordering the park?	√	√	√	√	Detectable by the top-down satellite view.	√

	Roads bordering the park	10. Are the width of the sidewalk/bike lane suitable for walking/cycling?	×	×	×	×	Perceptual item could not be accurately captured through remote viewing.	×
		11. Are there any obstacles on the sidewalk/bike lane that prevent you from moving on? *	×	×	×	×	Static images could not capture items that change over time.	×
	Public transport station	12. Are there any public transport stations close to the park?	√	√	√	√	Detectable by sight level view.	√
		13. How long is the walking or cycling time from the public transport station to the nearest park entrance point (min)? *	×	×	×	×	Could not be remote audited	×
	Parking lot	14. Are there any parking lots? (Specifically provided by the park.)	√	√	√	√	Detectable by the top-down satellite view.	√
		15. Are there any bicycle racks? (Specifically provided by the park.)	√	√	√	√	Detectable by sight level view.	√
		16. Is the parking free?	√	√	√	√	Detectable by sight level view.	√
		17. Is it convenient to parking? (Consider the entrance and exit signs, and parking management）	×	×	×	×	Perceptual item could not be accurately captured through remote viewing.	×
Activity areas	Sport court	18. What sports courts are in the park?	√	√	√	√	Detectable by the top-down satellite view.	√
		19. Are the sports court usable?	×	×	×	×	Static images could not capture items that change over time.	×
		20. Are the sports court free to use?	×	×	×	×	Could not be remote audited	×

	21. Are there any guidance or warning signs for sports court users?	√	√	√	√	Detectable by sight level view.	√
	22. Are there any benches to rest on?	√	√	√	√	Detectable by sight level view.	√
	23. Are there any shade areas or shelter in the sport court?	√	√	√	√	Detectable by sight level view.	√
	24. Are the sports court fenced?	√	√	√	√	Detectable by sight level view.	√
	25. Are the sports court in good condition?	×	×	×	×	Condition assessments could not be accurately captured through remote viewing.	×
	26. Are there any playgrounds in the park?	√	√	√	√	Detectable by the top-down satellite view.	√
	27. Are the playgrounds usable?	×	×	×	×	Static images could not capture items that change over time.	×
Playground	28. How many types of playgrounds equipment are present? (e.g., swings, seesaws, slides, trampolines, carousels, rock climbing, etc.)	×	×	×	×	It cannot be counted accurately due to the resolution	×
	29. Are there any guidance or warning signs for playground users?	√	√	√	√	Detectable by sight level view.	√
	30. Are the playgrounds in good condition? (Consider the cleanliness, management and safety)	×	×	×	×	Condition assessments could not be accurately	×

						captured through remote viewing.	
Running track	31. Are there any tracks specifically for running?	√	√	√	√	Detectable by sight level view.	√
	32. Are there any obstacles on the running tracks that prevent you from moving on? *	×	×	×	×	Static images could not capture items that change over time.	×
	33. Are the running tracks in good condition? (Consider the cleanliness, surface and management)	×	×	×	×	Condition assessments could not be accurately captured through remote viewing.	×
Fitness area	34. Are there any fitness areas in the park?	√	√	√	√	Detectable by sight level view.	√
	35. Are there any guidance or warning signs for fitness area users?	√	√	√	√	Detectable by sight level view.	√
	36. Are the fitness areas in good condition? (Consider the cleanliness, management and safety)	×	×	×	×	Condition assessments could not be accurately captured through remote viewing.	×
Public /Green space	37. Are there any public /green spaces in the park? (It is a space where people can freely access and conduct activities.)	√	√	√	√	Detectable by the top-down satellite view.	√
	38. Are the surface of the public /green spaces flat?	×	×	×	×	Perceptual item could not be accurately captured through remote viewing.	×

Facilities and amenities	Path	39. Are there any guidance or warning signs for public /green spaces users?	√	√	√	√	Detectable by sight level view.	√
		40. Are the public/green spaces in good condition? (Consider the cleanliness, safety, and maintenance)	×	×	×	×	Condition assessments could not be accurately captured through remote viewing.	×
		41. Are there any walking paths in the park?	√	√	√	√	Detectable by sight level view.	√
		42. Are the paths with the appropriate width for walking?	×	×	×	×	Perceptual item could not be accurately captured through remote viewing.	×
		43. Are there any obstacles on the path? *	×	×	×	×	Static images could not capture items that change over time.	×
		44. Are the paths sloping? *	×	×	×	×	Perceptual item could not be accurately captured through remote viewing.	×
		45. Are the paths in good condition? (Consider the cleanliness, maintenance and surface)	×	×	×	×	Condition assessments could not be accurately captured through remote viewing.	×
	Public toilet	46. Are there any public toilets in the park?	√	√	√	√	Detectable by sight level view.	√
		47. Are there any amenities offered in the toilets? (e.g., hand soap, hand towels, mirrors, toilet paper, etc.)	×	×	×	×	Could not be remote audited	×

	48. Are the public toilets in good condition? (Consider the cleanliness, maintenance and safety)	×	×	×	×	Condition assessments could not be accurately captured through remote viewing.	×
Shelter and pavilion	49. Are there any shelters and pavilions in the park?	√	√	√	√	Detectable by the top-down satellite view.	√
	50. Are there any benches to rest under the shelters and pavilions?	√	√	√	√	Detectable by sight level view.	√
	51. Are the shelters and pavilions in good condition? (Consider the cleanliness, safety and maintenance.)	×	×	×	×	Condition assessments could not be accurately captured through remote viewing.	×
Drinking fountain	52. Are there any drinking fountains in the park?	√	√	√	√	Detectable by sight level view.	√
	53. Are the drinking fountains usable?	×	×	×	×	Static images could not capture items that change over time.	×
Bench	54. Are there any benches to rest in the park? (Excluding all benches in themed areas such as sports courts, or playgrounds)	√	√	√	√	Detectable by the top-down satellite view.	√
	55. Are there any tree shades or coverage on the benches?	√	√	√	√	Detectable by sight level view.	√
	56. Are there any pleasant views while resting on the benches?	×	×	×	×	Perceptual item could not be accurately captured through remote viewing.	×

		57. Are the benches in good condition? (Consider the cleanliness, maintenance and comfort.)	×	×	×	×	Condition assessments could not be accurately captured through remote viewing.	×
	Picnic table	58. Are there any picnic tables in the park?	√	√	√	√	Detectable by sight level view.	√
		59. Are there any tree shades or coverage on the picnic table?	√	√	√	√	Detectable by sight level view.	√
		60. Are the picnic tables in good condition? (Consider the cleanliness, maintenance and comfort.)	×	×	×	×	Condition assessments could not be accurately captured through remote viewing.	×
	Trash can	61. Are there any trash cans in the park?	√	√	√	√	Detectable by sight level view.	√
		62. Are the trash cans easy to find in the park?	×	×	×	×	Perceptual item could not be accurately captured through remote viewing.	×
		63. Are the trash cans in good condition? (Consider the cleanliness, maintenance, and smell)	×	×	×	×	Condition assessments could not be accurately captured through remote viewing.	×
Aesthetic	Vegetation and landscape	64. How many species of vegetation can you identify in the park? (Including flowers and plants)	√	√	√	√	Detectable by sight level view.	√
		65. Has any vegetation and landscape in the park been uprooted or damaged? *	×	×	×	×	Static images could not accurately capture items that change over time.	×

		66. Are the vegetation and landscape in good condition? (Consider the management, mow, and design)	×	×	×	×	Condition assessments could not be accurately captured through remote viewing.	×
	Graffiti	67. Are there any graffiti (unauthorized writing or drawing on a public surface) in the park? *	×	×	×	×	Static images could not accurately capture items that change over time.	×
	Litter	68. Are there any litter in the park? (Do not consider litter inside the trash cans). *	×	×	×	×	Static images could not accurately capture items that change over time.	×
	Lighting	69. Are there adequate lighting in the park? (e.g., lighting in the most part of the park)	√	√	√	√	Item was adjusted to "Are there light posts in most areas of the park?" Detectable by sight level view.	√
	Surveillance equipment	70. Is there surveillance equipment in the park?	√	√	√	√	Detectable by sight level view.	√
Safety	Emergency device	71. Are there any emergency devices in the park? (e.g., fire alarms, fire hydrants, Automated External Defibrillators (AED), or health service stations)	√	√	√	√	Detectable by sight level view.	√
		72. Are the locations of any emergency equipment marked on the park map?	×	×	×	×	It could not be remote audited	×
	Warning sign	73. Are there any warning signs in the park? (e.g., no swimming, no smoking, and dogs are prohibited).	√	√	√	√	Detectable by sight level view.	√

	74. Are these warning signs clear?	√	√	√	√	Detectable by sight level view.	√

Remote audit tool composition and structure. After the detectable assessment of items and discussion with the research team, remote audit tool retains a total of 39 items applicable to the remote assessment, covering five dimensions: park surroundings and accessibility (11 items); activity areas (12 items); facilities and amenities (10 items); aesthetics (1 item); and safety (5 items). Since the remote audit method cannot determine the dynamic state or maintenance of facilities, items related to 'functionality' or 'maintenance status' were not retained, and only static, visual and objectively identifiable items were selected. Additionally, to ensure consistency and repeatability during remote audits, the original audit tool manual was rewritten to form a complete set of remote audit tool, and an audit guide was added, as shown in Appendix 4. The remote audit tool and the audit guide aim to reduce the variation of scores between auditors and provide a basis for subsequent reliability and validity tests.

5.2.4 Auditor training

In aligned with dense urban park audit tool, remote audit tool organised two days of auditors' training prior to the formal data collection. Both auditors were instructed in the operation of the system for both on-site and remote audits, focusing on the contents of the remote audit tool operating manual. The trainer systematically explained the adapted remote audit tool manual to the auditors. The manual listed in detail the definitions of all audit items, scoring standards and operation instructions, and was accompanied by picture examples and scoring tips.

During the training, the auditors were required to use Google Earth Pro to conduct remote audit simulations of two selected urban parks in Tokyo, Japan. The objective of this stage was to enhance the auditors' operational skills and to acquire the ability of image reading how to switch between different viewpoints (e.g. satellite view and street view) and make accurate judgement. In addition to the remote audits, the auditors were asked to conduct on-site audits of the same two urban parks as a control to compare the consistency of their scores with those of the remote audits. The formal data collection stage can only proceed once the auditor's scoring accuracy and agreement have been met. Audit data obtained during the training were used for learning and comparison practice only and were not included in the data analysis for the formal analysis of the study.

5.2.5 Data collection for reliability and validity

To evaluate the reliability and validity of the remote audit tool, data were collected through both remote and on-site audits. Prior to the assessment, the geographical locations and boundaries of each park were precisely identified. Subsequently, two trained auditors independently conducted remote audits of all 53 selected parks between 6 and 19 March 2024, using Google Earth Pro. Each auditor completed an audit form for every park, resulting in a total of 106 fully completed remote audit assessments. During this process, auditors also

recorded the date and duration of each audit to facilitate quality assurance and workload tracking.

In addition to the remote evaluations, on-site audits were carried out to enable a comparative analysis between the two methods. A random subsample of 25 parks was selected from the overall sample, ensuring a range of park types and neighbourhood contexts were represented. Both auditors independently on-site audit the same 25 parks using remote audit tool, mirroring the procedure used in the remote audits.

To mitigate the potential influence of recall bias on scoring, a minimum time interval of one month was maintained between the completion of the on-site and remote audits for each park. This time gap helped ensure that auditors' memories of specific park features did not unduly influence subsequent assessments, thereby strengthening the independence and objectivity of the evaluations.

5.2.6 Statistical analysis

Inter-rater reliability. Inter-rater reliability for both the remote and on-site audits was assessed by comparing the item-by-item responses of the two auditors. For evaluate the inter-rater reliability of remote audit tool, Cohen's kappa and weighted kappa statistics were employed, depending on the nature of the item. Kappa offer a robust measure of agreement between raters by accounting for the agreement that may occur purely by chance [134]. Specifically, Cohen's kappa was used for dichotomous items, while weighted kappa was applied to ordinal items to reflect the degree of disagreement. This approach ensured that all item types were evaluated using appropriate statistical methods. Interpretation of the kappa value is consistent with dense urban park audit tool following the widely adopted critical value proposed by Landis and Koch [135], categorising agreement levels as follows: "Almost perfect agreement" (0.81–1.00), "Substantial agreement" (0.61–0.80), "Moderate agreement" (0.41–0.60), "Fair agreement" (0.21–0.40), "Slight agreement" (0.00–0.20), and "Poor agreement" (<0.00). These classifications enabled a consistent and meaningful interpretation of reliability scores across the audit items.

In addition to kappa values, percent agreement was calculated for each item as a supplementary measure of inter-rater reliability, particularly for those items where limited variability in responses may affect the kappa statistic's stability [136]. A percent agreement threshold of 70% or above was considered acceptable, based on prior empirical standards in park audit research [122]. For each remote audit tool dimension, the average kappa and percent agreement were computed by taking the mean values of all items within that dimension.

Convergent validity. To examine the convergent validity of remote audit tool, the mean scores of the two auditors were calculated for each individual item. These mean scores were used as the final rating for each item. Composite scores were then derived by summing the mean item scores within each dimension. For examine the convergent validity of remote audit tool, the intra-class correlation coefficient (ICC) was calculated by comparing the remote and

on-site audit scores for the same 25 parks [137]. Both individual item scores and composite scores were included in the ICC analyses to evaluate consistency between the two audit methods. The interpretation of ICC values adhered to the guidelines proposed by Koo and Li [137] which define ranges for poor, moderate, good, and excellent validity. This helped ensure a rigorous and standardised assessment of validity. All statistical analyses were conducted using IBM SPSS Statistics version 29.

5.3 Results of remote audit adaptation

This subsection presents the key findings of the adaptation of remote audit tool. Kappa coefficient and percent agreement were used to assess the reliability of remote audit tool. ICC was employed to assess the convergent validity of remote audit tool by comparing the individual item and composite scores obtained from on-site and remote audits. This section presents two key results: 1) the reliability of the remote audit tool at the item level and at the dimension level; and 2) the validity of the remote audit tool at the composite level and at the item level.

5.3.1 Reliability of remote audit tool

Reliability at the item level. The inter-rater reliability results for remote audit tool are summarised in Table 5.2, which presents the kappa statistics and percent agreement for each of the 39 audit items across both remote and on-site assessments. kappa scores were successfully calculated for 36 of the 39 items in the remote audit, and for 22 items in the on-site audit. For several items, kappa values could not be computed due to a lack of variability in auditor responses—typically where all raters gave identical scores. However, for these items, the percent agreement reached 100%, indicating complete consistency in scoring.

Among the remote audit items, one exhibited a kappa value between 0.21 and 0.40, representing fair inter-rater agreement. Thirteen remote items and three on-site items fell into the moderate agreement category (kappa 0.41–0.60). Notably, 17 remote audit items and two on-site items achieved substantial agreement with kappa values ranging from 0.61 to 0.80. Furthermore, five remote audit items and 17 on-site items demonstrated almost perfect agreement, with kappa values exceeding 0.81. These findings reflect strong consistency between raters across a broad range of environmental attributes assessed using remote audit tool.

Among all items, playgrounds and benches in the remote audit attained the highest inter-rater reliability, with perfect kappa values of 1.00, indicating total agreement between auditors. In contrast, the item on shelters and pavilions had the lowest remote audit kappa score, recorded at 0.37, which still reflects fair agreement. Figure 5.5 illustrates the performance of both the highest- and lowest-reliability items across remote and on-site audits to visually contextualise these findings. Percent agreement across all remote audit tool items exceeded 70%, further

supporting the overall reliability of the tool. This suggests that even for items with limited variability that reduced the applicability of kappa, the agreement between raters remained consistently high.

Table 5.2. Inter-rater reliability of items (remote $N = 53$, on-site $N = 25$)

Remote audit tool items	Inter-rater reliability			
	Remote audit		On-site audit	
	Kappa	Percent agreement	Kappa	Percent agreement
Park surroundings and accessibility				
How many entrance points are there to access the park smoothly?	0.66	96%	NA	100%
Are there any signs showing the location or directions to the park?	0.74	88%	1.00	100%
Are there any park information at the entrance points?	NA	100%	NA	100%
Are there any crosswalks on the road to access the park?	0.79	98%	NA	100%
Are there any traffic lights on the crosswalk?	0.63	92%	1.00	100%
Are there any signs of speed limit on the roads to access the park?	0.70	94%	NA	100%
Are there sidewalks/bike lanes on the roads bordering the park?	0.65	96%	NA	100%
Are there any public transport stations close to the park?	0.65	96%	NA	100%
Are there any parking lots?	0.79	92%	1.00	100%
Are there any bicycle racks?	0.42	82%	1.00	100%
Is the parking free?	0.70	85%	1.00	100%
Activity areas				
What sports courts are in the park?	0.88	94%	1.00	100%
Are there any guidance or warning signs for sports court users?	0.82	92%	0.64	95%
Are there any benches to rest on?	0.83	94%	1.00	100%
Are there any shade areas or shelters in the sport court?	0.63	84%	NA	100%
Are the sports court fenced?	0.77	90%	1.00	100%
Are there any playgrounds in the park?	1.00	100%	1.00	100%
Are there any guidance or warning signs for playground users?	0.44	73%	1.00	100%
Are there any tracks specifically for running?	0.54	78%	1.00	100%
Are there any fitness areas in the park?	0.69	84%	1.00	100%

Are there any guidance or warning signs for fitness area users?	0.51	76%	NA	100%
Are there any public /green spaces in the park?	0.66	98%	NA	100%
Are there any guidance or warning signs for public /green spaces users?	0.50	90%	NA	100%
Facilities and amenities				
Are there any walking paths in the park?	0.48	96%	NA	100%
Are there any public toilets in the park?	NA	100%	NA	100%
Are there any shelters and pavilions in the park?	0.65	96%	1.00	100%
Are there any benches to rest under the shelters and pavilions?	0.37	94%	NA	100%
Are there any drinking fountains in the park?	0.65	96%	NA	100%
Are there any benches to rest in the park?	1.00	100%	NA	100%
Are there any tree shades or coverage on the benches?	0.45	78%	0.60	80%
Are there any picnic tables in the park?	0.46	84%	1.00	100%
Are there any tree shades or coverage on the picnic table?	0.43	86%	0.53	76%
Are there any trash cans in the park?	0.73	92%	1.00	100%
Aesthetics				
How many species of vegetation can you identify in the park?	0.65	96%	0.65	96%
Safety				
Are there light posts in most areas of the park?	0.48	73%	0.58	84%
Is there surveillance equipment in the park?	0.50	82%	1.00	100%
Are there any emergency devices in the park?	0.54	80%	1.00	100%
Are there any warning signs in the park?	NA	100%	NA	100%
Are these warning signs clear?	0.52	86%	NA	96%

Note. NA: not available, if item responses lacked sufficient variability.

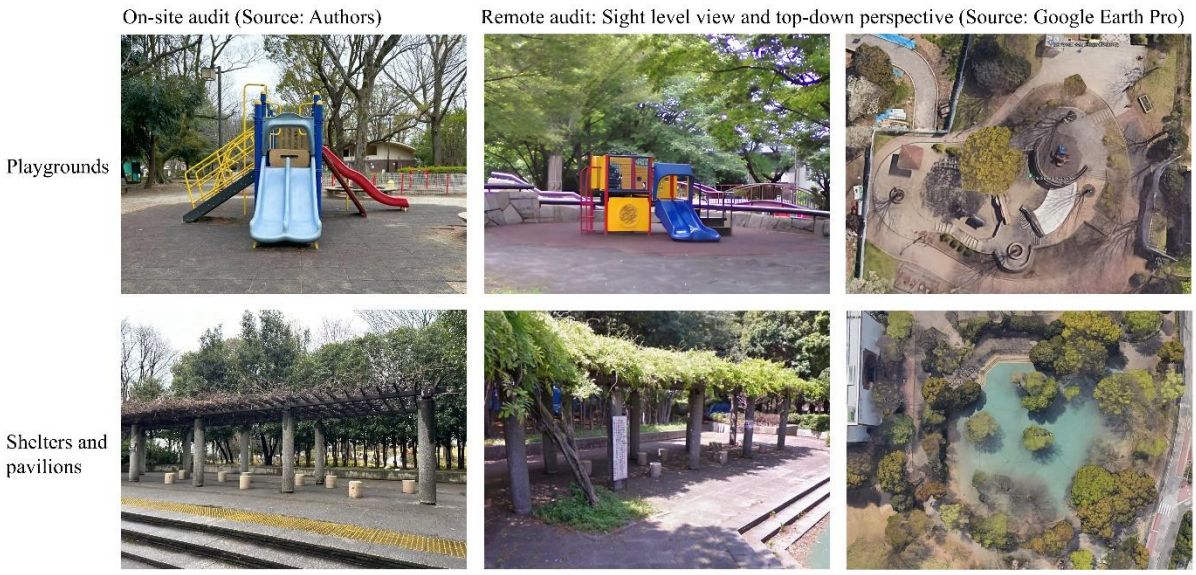

Figure 5.5. Highest and lowest reliability items on on-site and remote audits

Reliability at the dimension level. Table 5.3 and Table 5.4 report inter-rater reliability by dimension for both audit methods. The average kappa scores across of remote audit for five dimensions ranged from 0.40 to 0.80, indicating moderate to substantial agreement. The activity areas dimension demonstrated the highest average kappa at 0.69, suggesting that features related to physical activity spaces were relatively easier to identify and assess remotely. Conversely, the safety dimension yielded the lowest average kappa at 0.51, reflecting potential challenges in evaluating nuanced safety features via Google Earth Pro. Percent agreement for each dimension in the remote audit was uniformly high, ranging from 84% to 96%. The aesthetics dimension showed the highest percent agreement at 96% and the safety dimension had the lowest at 84%. Similarly, on-site audit also showed strong inter-rater agreement, with kappa scores across dimensions ranging from 96% to 100%, indicating moderate to almost perfect agreement. The overall kappa score was 0.62 for remote and 0.86 for on-site audits, while the overall percent agreements were 91% and 98%, respectively.

Collectively, these results indicate that remote audit tool demonstrates good to excellent inter-rater reliability for both remote and on-site audits. These findings support the robustness of the tool for consistent environmental assessment across multiple raters and settings.

Table 5.3. Inter-rater reliability of dimensions (remote *N* =53).

Dimensions	Criteria (N)	Items (N)	Inter-rater reliability						
			Kappa				Percent agreement		
			Not applicable	Average kappa	N>0.40 kappa	%>0.40 kappa	Average agreement	N>70% agreement	%>70% agreement
Park surroundings and accessibility	5	11	1	0.67	10	100%	93%	11	100%
Activity areas	5	12	0	0.69	12	100%	88%	12	100%
Facilities and amenities	7	10	1	0.58	8	88%	92%	10	100%
Aesthetics	1	1	0	0.65	1	100%	96%	1	100%
Safety	4	5	1	0.51	4	100%	84%	5	100%
Total	22	39	3	0.62	35	98%	91%	39	100%

Table 5.4. Inter-rater reliability of dimensions (on-site *N*=25).

Dimensions	Criteria (N)	Items (N)	Inter-rater reliability						
			Kappa				Percent agreement		
			Not applicable	Average kappa	N>0.40 kappa	%>0.40 kappa	Average agreement	N>70% agreement	%>70% agreement
Park surroundings and accessibility	5	11	6	1.00	5	100%	100%	11	100%
Activity areas	5	12	4	0.96	8	100%	100%	12	100%
Facilities and amenities	7	10	5	0.82	5	100%	96%	10	100%
Aesthetics	1	1	0	0.65	1	100%	96%	1	100%
Safety	4	5	2	0.86	3	100%	96%	5	100%
Total	22	39	17	0.86	22	100%	98%	39	100%

5.3.2 Validity of remote audit tool

Validity of at the composite level. To evaluate the convergent validity of remote audit tool, comparisons were made between the remote and on-site audits of 25 parks. The mean composite score derived from on-site audit was 38.42 (SD = 3.61), while the corresponding mean score from the remote audit was slightly lower at 37.29 (SD = 3.72). ICC between these two audit methods of composite scores was 0.73 ($p < 0.001$), indicating a moderate level of correlation between the remote and on-site methods. This finding suggests that remote audit tool, when applied remotely via Google Earth Pro, can produce results that are reasonably consistent with those obtained from direct field observations. Notably, 89.74% of the composite scores for individual parks differed by fewer than three points between the two audit methods, reflecting a high degree of agreement at the overall tool level. This small margin of variation further supports the validity of remote assessments for capturing essential park features relevant to physical activity promotion.

Validity of at the item level. At the individual item level, remote audit scores were found to be identical to on-site scores for 14 out of the 39 remote audit tool items, indicating excellent alignment between the two data collection methods for a substantial proportion of items. Moreover, significant positive correlations ($p < 0.05$) between remote and on-site audit scores were observed for 19 items. Among these, the strongest correlation was found for the item "Are there any parking lots?", which achieved a correlation coefficient of 0.98, demonstrating almost perfect concordance between the two audit modes. In contrast, the lowest observed correlation was for the item "Is there surveillance equipment in the park?", with a coefficient of 0.35, which still indicates a weak positive correlation. This disparity is likely due to the inherent limitations of satellite and street view imagery in detecting smaller or less visible features, such as security cameras, especially when partially obscured or poorly illuminated in available views. Figure 5.6 illustrates the performance of the highest and lowest correlating items to visually demonstrate the degree of validity variation across the tool. The complete set of item-level correlation results is detailed in Table 5.5.

Figure 5.6. Items with the highest and lowest ICC from the on-site and remote audits

Table 5.5. The correlation of on-site and remote audits.

Remote audit tool items	**ICC [a]**	***P***
Park surroundings and accessibility		
How many entrance points are there to access the park smoothly?	1.00	NA
Are there any signs showing the location or directions to the park?	-0.20	0.84
Are there any park information at the entrance points?	1.00	NA
Are there any crosswalks on the road to access the park?	1.00	NA
Are there any traffic lights on the crosswalk?	0.59	<0.001
Are there any signs of speed limit on the roads to access the park?	-	NA
Are there sidewalks/bike lanes on the roads bordering the park?	1.00	NA
Are there any public transport stations close to the park?	-	NA
Are there any parking lots?	0.98	<0.001
Are there any bicycle racks?	0.68	<0.001
Is the parking free?	0.91	<0.001
Activity areas		
What sports courts are in the park?	0.63	<0.001
Are there any guidance or warning signs for sports court users?	0.76	<0.001
Are there any benches to rest on?	0.73	<0.001
Are there any shade areas or shelters in the sport court?	0.75	<0.001
Are the sports court fenced?	0.72	<0.001
Are there any playgrounds in the park?	-	NA
Are there any guidance or warning signs for playground users?	0.16	0.21
Are there any tracks specifically for running?	0.78	<0.001
Are there any fitness areas in the park?	0.74	<0.001

Are there any guidance or warning signs for fitness area users?	0.50	0.00
Are there any public /green spaces in the park?	1.00	NA
Are there any guidance or warning signs for public /green spaces users?	-	NA
Facilities and amenities		
Are there any walking paths in the park?	-	NA
Are there any public toilets in the park?	1.00	NA
Are there any shelters and pavilions in the park?	0.66	<0.001
Are there any benches to rest under the shelters and pavilions?	0.61	<0.001
Are there any drinking fountains in the park?	-	NA
Are there any benches to rest in the park?	1.00	NA
Are there any tree shades or coverage on the benches?	0.32	0.06
Are there any picnic tables in the park?	0.83	<0.001
Are there any tree shades or coverage on the picnic table?	0.66	<0.001
Are there any trash cans in the park?	0.94	<0.001
Aesthetics		
How many species of vegetation can you identify in the park?	0.92	<0.001
Safety		
Are there light posts in most areas of the park?	0.31	0.06
Is there surveillance equipment in the park?	0.35	0.04
Are there any emergency devices in the park?	0.30	0.07
Are there any warning signs in the park?	1.00	NA
Are these warning signs clear?	-0.05	0.60
Composite scores	0.73	<0.001

Note. [a] Intra-class correlation coefficient; -: Cannot be computed because at least one of the variables is constant; NA: Not available.

Overall, these results indicate that remote audit tool demonstrates acceptable convergent validity, with remote audits offering a reliable alternative to on-site observations for most items. However, it is acknowledged that certain park attributes—particularly those related to small-scale infrastructure or condition-sensitive elements—may be less effectively captured through remote means. These limitations should be considered when interpreting remote audit data or designing future adaptations of similar assessment tools.

5.4 Discussions of remote audit tool adaptation

5.4.1 Innovations of remote audit tool

The results of remote audit tool testing are consistent with previous findings regarding the performance of remote auditing tools. Tools such as the Microscale Audit of Pedestrian Streetscapes (MAPS) [123] and the Madrid Systematic Pedestrian and Cycling Environment

Scan (M-SPACES) [138] also demonstrated sufficient levels of reliability following the adaptation of items from their original on-site versions. However, unlike these existing tools, remote audit tool is the first remote audit tool specifically developed for assessing urban parks in dense Asian cities [42]. It addresses a research gap by focusing on the unique characteristics of park in dense urban settings in Asia and aims to provide an evidence-based foundation for park renewal to enhance physical activity.

5.4.2 Challenges of remote audit tool

Due to the inherent limitations of remote images—such as their static nature and resolution constraints—several original audit tool items were not suitable for virtual assessment. As a result, these items were either modified or excluded in remote audit tool. The most significant adjustments were made to the aesthetics dimension. One reason for these modifications is that virtual audits often suffer from obstructed views or low image quality, making it difficult to detect small-scale features such as graffiti [139]. Additionally, static images cannot assess elements that vary over time, such as litter or damaged facilities [48]. These limitations align with previous research that recommends omitting such items to improve audit reliability [123]. Nevertheless, remote audit tool retains the essential components of dense urban park audit tool, excluding only items like graffiti and litter, while still maintaining a comprehensive and representative structure.

5.4.3 Reliability findings of remote audit tool

For inter-rater reliability, most remote audit tool items exhibited moderate to almost perfect agreement in both remote and on-site audits. These results are comparable to previous studies [48, 127], which also reported high reliability for items that are large, brightly coloured, and easily identifiable—such as playgrounds, benches, and sports courts. These features are generally easier to detect through satellite and street view images, reducing subjectivity in assessments. Conversely, items that are often obscured or partially hidden—such as benches under shelters or light poles—tended to yield lower reliability scores, which is also consistent with existing literature. Furthermore, items using binary response formats (e.g. presence or absence) achieved higher agreement than those requiring scaled judgments, confirming previous findings that dichotomous items reduce subjectivity and improve inter-rater consistency [136].

5.4.4 Validity performances of remote audit tool

The remote and on-site audits produced moderately to strongly correlated scores for both individual items and composite scores (ICC = 0.73), supporting the convergent validity of

remote audit tool. Among the 39 items assessed, 14 showed identical scores across the two audit methods, and 89.74% of composite scores differed by fewer than three points between the remote and on-site audits. These findings indicate that remote audit tool provides a consistent assessment of park attributes. Nevertheless, some items exhibited weaker correlations, such as the presence of surveillance equipment and the availability of instructional or warning signs in fitness zones. A possible explanation is that remote image data may not reflect the most recent updates in the physical environment, leading to discrepancies with on-site observations [126]. Moreover, the lower image resolution in remote audits may reduce the level of detail available for assessment, resulting in reduced the validity [136]. Since remote image data captures the perceptual and aesthetic attributes of park environments, integrating artificial intelligence and other data sources could enhance the validity of remote audit tool in the future. For example, computer vision algorithms could be used to identify litter, graffiti, or greenery coverage in images, as well as natural language processing to analyse people's perceptions of cleanliness and safety in parks on social media.

5.5 Summary

This chapter described the process of adapting the original dense urban park audit tool into a remote auditing format to assess park attributes that support physical activity in dense urban areas. The adaptation involved a pilot test and researchers' consultation, ensuring feasibility for virtual assessment. The reliability and validity of remote audit tool were systematically evaluated through inter-rater comparisons and by correlating remote and on-site audit results. Most items and all five dimensions demonstrated moderate to almost perfect inter-rater reliability, and convergent validity was supported by strong consistency between remote and on-site composite scores. High-reliability items were typically large, bright, and dichotomously scored, while items that were visually obstructed or image-quality dependent showed lower reliability. remote audit tool proved to be a reliable and valid alternative to on-site audits.

The adaptation from dense urban park audit tool to remote audit tool is not only an alternation of technical paths, but also an expansion and innovation of urban space assessment methodology. Remote audit tool provides a low-cost, high-efficiency and reviewable data collection means for subsequent research on urban environment and health behaviour and creates the conditions for improving the scientific basis of urban public space governance and design practice.

Chapter 6 Conclusion

6.1 Overview of the thesis

The aim of this thesis is to develop and validate an on-site and remote audit tool for dense urban areas, allowing the assessment of park environments that support physical activity. The study unfolds through several key stages, each of which is systematically presented in the appropriate chapter.

Chapter 1 introduces the context and the significance and purpose of this thesis. The role of parks in promoting physical activity and health and well-being is emphasised, as well as the important role of the audit tool as an objective assessment tool to provide objective data to support the renewal and design of parks.

Chapter 2 systematically reviews existing direct observation audit tools and identifies three major research gaps in the adaptability to urban context, the applicability to culture and the user-friendliness of their existing audit tools. A theoretical basis is provided for the development of a new audit tool.

Chapter 3 details the development process of dense urban park audit too, including the construction of the assessment framework, the importance assessment of the assessment framework, the quantitative assessment criteria, the pilot testing phase, and the modification and finalisation of dense urban park audit too.

Chapter 4 reports on the validation of the reliability and validity of the dense urban park audit too. It covers the selection of the study case, auditor training, on-site auditing and data collection, and statistical analyses of reliability and validity. The results show that dense urban park audit too demonstrates good reliability and validity as an environmental assessment tool for parks in dense urban areas.

Chapter 5 describes the process of adapting dense urban park audit too to the remote audit version, using Google Earth Pro for virtual assessment. The chapter covers item adaptation, auditor training, data collection methods, and statistical analyses used to assess reliability and validity. The results indicate that remote audit tool is both a reliable and valid tool for remotely assessing park environmental attributes that support physical activity.

In conclusion, this thesis develops a theoretically based and empirically supported park audit tools: dense urban park audit tool and remote audit tool, that fills a gap in research and practice in the application of dense urban areas, Asian cultures, and user-friendly park assessment methods.

6.2 Strengths

This thesis demonstrates significant strengths in the rigour of the entire process of developing, validating, and remotely adapting the dense urban park audit tool, as well as in the systematic and innovative nature of its research methodology and theoretical contributions.

6.2.1 Scientific pathway and framework

In research process, this study systematically went through three key phases: the development of the dense urban park audit tool, the testing of the dense urban park audit tool, and remote adaptation, as shown in Figure 6.1. The development phase was grounded in a systematic literature review, which identified the limitations of existing audit tools and the research gaps within the field. Based on this, a theoretical framework was constructed. Expert scoring was employed to select key criteria, leading to the development of quantifiable and well-structured audit items. Dense urban park audit tool was then refined and optimised through pilot testing. Subsequently, reliability and validity tests were conducted in 25 parks, confirming dense urban park audit tool's suitability for assessing park environments in dense urban areas. During the remote adaptation phase, dense urban park audit tool's applicability was further extended through the development of remote audit tool—a remote-based version tailored for high-density city contexts. Its feasibility and reliability were empirically tested and confirmed. This whole process highlights the ability of this thesis to build a coherent and powerful framework from dense urban park audit tool development, verification, to remote adaptation. It establishes a scientific and systematic methodological path.

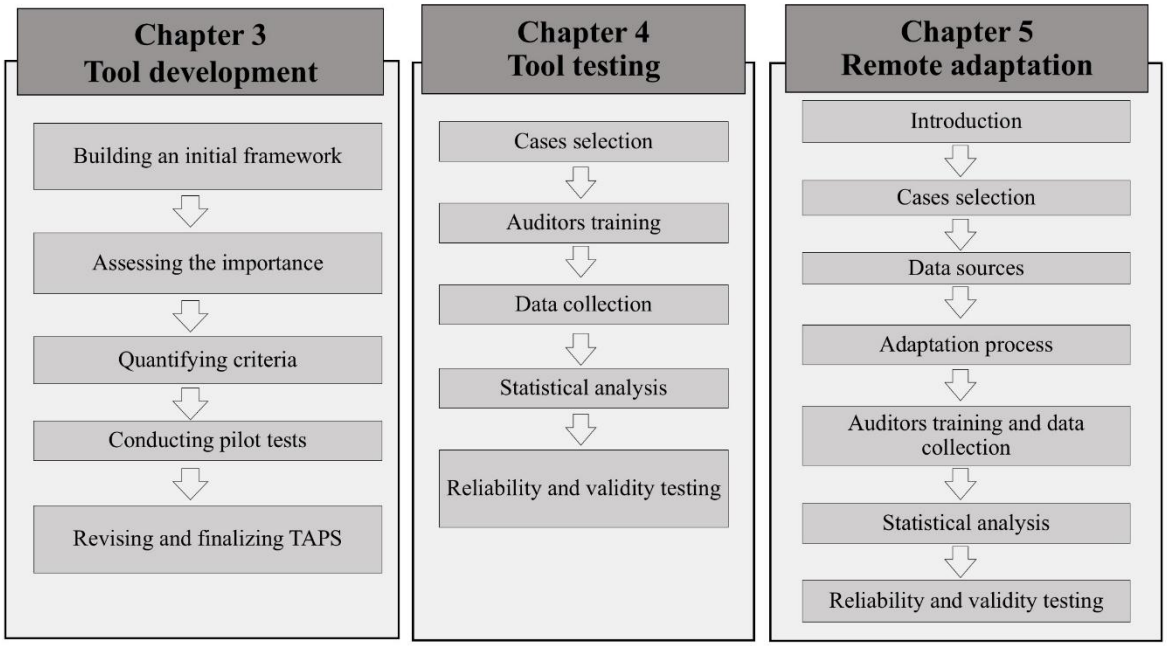

Figure 6.1. Three key phases of thesis

First, a systematic review of the literature is the first step in the dense urban park audit tool development process. This stage has two important implications. The first significance is that it reveals the commonly used dimensional components and audit items in existing audit tools, such as facilities, security, and accessibility. More critically, it reveals the research gaps that exist in these existing audit tools, especially in the application to the issues of environmental adaptability in dense urban environments, Asian cultural adaptation, and diversity of intense users. Most of these tools originate from low-density Western urban contexts and lack adaptability to Asian urban environments that are spatially tight, functionally mixed, and have diverse cultural usage patterns. Thus, this empirical evidence-based problem identification set a clear research objective for the development of dense urban park audit tool.

Constructing a clear assessment framework as a core structure was the second step in the development of dense urban park audit tool. Based on the literature review, a hierarchical framework for assessing park environmental attributes affecting physical activity was constructed. The framework consists of five dimensions: park surroundings and accessibility, activity areas in park, park facilities and amenities, aesthetics, and park safety, and 31 environmental criteria. The core assessment framework developed as part of the dense urban park audit tool not only enhances the structure and organization of dense urban park audit tool but also provides summarized information for future research on park environmental attributes that influence physical activity.

Assessment of the importance of the criteria in the framework and consensus building is the third step in the development of dense urban park audit tool. In this study, experts from the interdisciplinary fields of urban design, public health, environmental psychology, and park management were invited to assess the importance of the criteria and reach. A fuzzy Delphi method was used to calculate the consensus values reached by the experts to ensure the scientific and practicality of the criteria. The purpose of the importance assessment and consensus value analysis was to emphasize the applicability of the assessment framework in dense urban areas and the adaptability to Asian cultures. The finalized 24 criteria cover the five dimensions mentioned above.

Converting the 24 key criteria into quantifiable audit items was the fourth step in the development of dense urban park audit tool. A total of 88 items were generated by assessing different aspects of the criteria, such as presence, usability, quantity, quality, maintenance, and general condition, and quantifying them using a dichotomous and three-point scale response format. This step simplifies the assessment process, ensures that it is accessible to non-specialized users (e.g., community volunteers), expands the audience for the tool, and emphasizes the diversity of potential dense urban park audit tool users.

The fifth step in the development of dense urban park audit tool was the pilot field test of the 88 items generated and their modification. The purpose was to test the comprehensibility and ease of operation of the items with respect to possible problems in practical application. Based on auditor feedback and observed assessment biases, individual items were modified and optimized for language and structure. This iterative process has significantly improved

dense urban park audit tool 's operability and user experience.

After completing the development of the dense urban park audit tool, another highlight of the thesis was the stringent reliability and validity testing of the dense urban park audit tool. The field test was conducted in 25 different types of parks in Tokyo, and Cohen's kappa coefficient and percent agreement were used to assess the consistency between auditors, with 91.1% of the items achieving a kappa > 0.4 (moderate and above consistency), and 95.9% of the items achieving more than 70% consistency. This result fully proves that dense urban park audit tool has good scoring consistency and assessment stability. At the same time, the use of expert assessment results as the “gold standard” comparison verifies the convergent validity of the tool and ensures that the assessment results are theoretically and practically accurate.

Finally, this thesis successfully adapts dense urban park audit tool to a geographic information-based remote assessment version, using Google Earth Pro for virtual auditing. This transformation responds to the urgent need for a non-contact, low-cost, and efficient auditing methodology. Remote audit tool retains the theoretical structure of dense urban park audit tool and adapts and screens items suitable for satellite image observation. The test and application results in 53 parks showed that 89% of the items achieved moderate to high inter-auditor agreement, and the ICC between remote and field audit results was 0.73, indicating a high positive correlation between their assessment results. The development of remote audit tool not only proves the flexible adaptability of dense urban park audit tool but also provides an example of technological transformation for the study of urban environmental assessment.

In conclusion, from the construction of objectives based on research gaps, the design of the assessment framework, the field validation to the technology translation, the research process of this thesis demonstrates a rigorous research design, a profound problem orientation and a high degree of application prospect. This thesis not only fills the research gap of park audit tool in the dense urban context but also establishes a complete tool development pathway with scientific validity, replicability, and practical applicability. The success of dense urban park audit tool and remote audit tool provides a strong methodological foundation for future assessments of healthy urban environments and shows how urban design can be instrumentalized to promote the health of its residents as a policy practice.

6.2.2 Urban setting applicability and cultural adaptability

Dense urban park audit tool offers notable advantages in both urban setting applicability and cultural adaptability. As a newly developed park audit tool, one of its greatest strengths lies in its high degree of contextual relevance and cultural sensitivity, making it particularly well-suited to the complex urban fabric and unique physical activity preferences characteristic of dense Asian cities.

First, unlike most existing audit tools, which were primarily developed in low-density Western contexts, dense urban park audit tool has been specifically designed to account for key contextual features in dense urban areas, such as spatial constraints, multifunctional land use,

and the diverse behavioural patterns of urban residents in Asia. Previous audit tools have often set assessment criteria based on park structures in Western countries or cities with large areas and clear functional zoning, making it difficult to effectively capture the spatial characteristics of small-, medium-, and multi-purpose parks in Asian cities. By systematically integrating the five dimensions of activity area, facilities, accessibility, safety and aesthetics into the audit framework, dense urban park audit tool ensures a detailed assessment of the highly interlocking spaces in a variety of parks with different functions. The development of dense urban park audit tool to reliably and effectively assess such spaces greatly enhances the broad applicability of dense urban park audit tool in dense urban areas.

Second, the design of dense urban park audit tool deeply reflects an understanding of and response to physical activity preferences in the Asian cultural context. Unlike individualized, self-directed physical activity in Western cities, residents of Asian cities prefer collective, interactive activity modes such as morning square dancing, group gymnastics, Tai Chi practice, and family walks. Therefore, dense urban park audit tool introduces the item of assessable informal activity space in the activity area dimension, which can be used by residents to freely engage in group or interactive physical activities, thus more closely resembling the real use contexts in Asian cultures.

Finally, the dense urban park audit tool scoring system utilizes a simplified approach that dramatically improves the user-friendliness of dense urban park audit tool. This facilitates the participation of city managers, community groups and even resident volunteers in the assessment process. This design both lowers the operational threshold and provides a realistic possibility for promoting environmental improvements in parks in culturally diverse and institutionally decentralized Asian cities.

In summary, dense urban park audit tool is designed to meet the needs of dense urban environments in terms of content, reflecting a deep understanding of Asian usage behaviours and preferences in terms of culture, and possessing simplicity and user-friendliness in terms of the scoring structure. These characteristics make dense urban park audit tool not only a powerful tool to meet the current challenges of assessing physical activity spaces in dense urban environments but also provide a theoretical basis and a practical path for promoting healthy cities and culturally adaptive design in the future.

6.2.3 Evolution of reliable and valid methodology

The successful adaptation of the dense urban park audit tool to the remote version demonstrates the flexibility and practical sustainability of this assessment method. The development of remote audit tool provides a low-cost solution for monitoring and assessment of urban environments in urban environmental research and practice, where field surveys are limited by space, time, and labour costs, and there is a growing demand for remote environmental assessments. Remote audit tool is based on street view images and satellite data for auditing park environments, which is both cost effective and highly replicable and time

sensitive.

This thesis provides a detailed overview of the key steps in converting dense urban park audit tool from an onsite assessment tool to a remote assessment tool. A systematic adaptation process was established for the steps including image source selection, case selection, adjustment of remote audit items through pilot testing, audit training, data receipt and statistical analysis. Subsequently, the reliability and validity of remote audit tool were validated by applying it to 53 urban parks in Tokyo using kappa coefficient and ICC. The results showed that remote audit tool met the standard of "moderate" to "high" agreement in most of the items, ensuring its scientific validity and applicability.

The adaptation from dense urban park audit tool to remote audit tool is not only an alternation of technical paths, but also an expansion and innovation of urban space assessment methodology. Through systematic screening, reconstruction and validation, a set of remote audit tool has been developed, which is applicable to dense urban park environments, based on satellite imagery and street view technology, and can be operated. The construction of remote audit tool provides a low-cost, high-efficiency and reviewable data collection means for subsequent research on urban environment and health behaviour and creates the conditions for improving the scientific basis of urban public space governance and design practice.

6.2.4 Planning practice implications of audit tool

Dense urban park audit tool and remote audit tool, as proven park assessment tools specifically designed for dense urban areas, provide urban planners and policymakers with objective, evidence-based support for promoting active lifestyles among residents in the context of dense urban areas in Asia.

First, park renewal and design based on a standardised framework. Our audit tool provides a standardised environmental structure framework for assessing parks in dense urban environments. Urban designers, local governments, and landscape planners can use this framework to identify existing park attributes that may promote or hinder physical activity. Based on the assessment results, targeted interventions can be developed to enhance the important role of parks in promoting physical activity among residents. Second, promoting community participation. The audit tool developed in this study is specifically designed to be user-friendly and easy to use for non-professional users, including residents and community stakeholders. This inclusiveness enables participatory audits, allowing local users to participate in data collection for parks and express their preferences. The research results can serve as a basis for community-based collaborative decision-making on park optimisation. Third, low-cost audit data collection. The remote audit method developed in this study provides an efficient alternative to on-site audits by utilising satellite data. For local governments and non-governmental organisations with limited resources, it enables the assessment and monitoring of multiple park environments at low cost.

In summary, dense urban park audit tool and remote audit tool are practical tools that

bridge health research and urban design. They are well suited for developing strategies for park environment improvements to promote active, sustainable lifestyles in dense urban areas.

6.3 Limitations

Despite the notable strengths of this thesis, several limitations should be acknowledged. Based on the process of dense urban park audit tool development, validation and remote adaptation, the research limitations of this thesis are discussed.

First, while dense urban park audit tool was developed as a user-friendly tool intended to be accessible to a diverse group of users, including laypersons, community members, professionals, and researchers. The use of simplified response formats, such as dichotomous and 3-point scales, may limit the granularity of data and reduce response selectivity compared to more detailed measurement instruments. This may restrict its sensitivity in capturing subtle environmental variations across park settings.

Second, in the field validation phase, the trainer's assessments were used as the 'gold standard' for evaluating inter-rater reliability. Although this approach ensured consistency in comparison, it may have introduced a degree of subjective bias. Discrepancies observed between the trainer's scores and other raters highlight the importance of comprehensive and standardised training for all users to minimise inter-rater variability and ensure replicability.

Third, seasonal factors affecting the park environment deserve careful attention. In this study, most on-site audits were conducted under favorable weather conditions, typically during sunny days in spring and summer. As a result, the observed condition of many park attributes appeared optimal. However, environmental features can vary considerably across seasons. For example, subjective items such as perceived cleanliness and aesthetics can be influenced by weather conditions, vegetation changes, and seasonal maintenance schedules. Although auditors were asked to conduct simultaneous assessments to reduce low reliability risks, seasonal variability may have affected the validity of the audit results. It is therefore recommended that future applications of dense urban park audit tool and remote audit tool incorporate repeated audits across different seasons to strengthen the interpretation and robustness of validity outcomes.

Fourth, the generalisability of dense urban park audit tool is limited by its initial development and testing within the specific urban context of Tokyo. While dense urban park audit tool was tailored to the unique spatial constraints and cultural characteristics of high-density Japanese cities, its applicability to other urban contexts in Asia or globally requires further empirical validation. Although cities in Asia often share similar features—such as high population density and limited public open space—cross-contextual studies are essential to confirm dense urban park audit tool's broader relevance and transferability.

Finaly, specific limitations are associated with the remote audit version. The use of Google

Earth Pro as the sole data source introduces limitations in data timeliness, as the virtual imagery may not reflect recent changes to the built environment. While the built environment is generally slow to change, this lag can nevertheless affect the reliability of virtual assessments. Moreover, relying on a single imagery source may limit the richness of contextual information. Although prior studies have noted that supplementing with sources like Google Street View or official municipal websites can increase audit depth, such sources were not used due to availability constraints or lack of functional data. In additionally, some important park characteristics that are known to influence recreational walking—such as litter, graffiti, or social disorder—cannot be reliably assessed using aerial or satellite imagery. This limits the comprehensiveness of remote audit tool in capturing aspects of park quality. To address these limitations, future studies could incorporate the use of AI and other data sources. Several potential directions include: 1) Computer Vision Algorithms. AI-based image recognition models can be trained to detect specific environmental features such as greenery coverage, surface damage, presence of litter, or graffiti; 2) Remote Sensing and Sensor-Based Data. Satellite imagery and urban sensing networks could be used to collect environmental attributes such as urban heat islands, lighting levels, or vegetation indices, which are indirect but relevant factors of park quality and aesthetics; 3) Natural Language Processing applications. Online reviews and social media posts related to public open spaces can be analysed using natural language processing techniques to extract users' perceptions of cleanliness, safety, attractiveness, or overall satisfaction. While these AI-enhanced methods are still in developmental stages and may not yet be fully integrated into standard remote audit tools, they present promising avenues for augmenting the objectivity and comprehensiveness of remote park assessment.

Nonetheless, these limitations should be viewed considering the pioneering nature of this study. dense urban park audit tool and remote audit tool represent the first audit tools developed specifically for use in dense urban environments in Asia, and their validated reliability contributes significantly to the feasibility of both on-site and virtual park audits. Future research should aim to refine response scales, expand geographic applicability, and integrate multiple data sources to further enhance the tools' robustness and utility.

6.4 Contributions to Knowledge Science

This thesis has demonstrated and promoted the theoretical development and practical application of Knowledge Science through the development, validation, and remote adaptation of dense urban park audit tool. Under the guidance of the basic concept of Knowledge Science, which emphasizes "from Knowledge to Action", this thesis not only systematically generates new knowledge about the relationship between urban environmental assessment and physical activity, but also successfully transforms this knowledge into a practical tool through the development, validation, and remote adaptation of dense urban park audit tool, showing a complete knowledge transformation pathway from theoretical development to practical application.

6.4.1 Knowledge generation

From a knowledge generation perspective, the thesis thoroughly analyses the application scope, and research limitations of current environmental audit tools for parks through a systematic literature review in the preliminary stage. In particular, it is pointed out that the majority of these tools originate from low-density Western urban contexts, and there are three key research gaps: urban context applicability, Asian cultural applicability, and user-friendliness, which make it difficult to meet the assessment needs of dense Asian urban contexts. This knowledge generation fills a gap in the understanding of the relationship between park environment and physical activity in dense urban contexts and lays a strong theoretical foundation for further dense urban park audit tool development.

6.4.2 Knowledge structure

Regarding the structuring of Knowledge, based on a systematic literature review to analyse the components of the existing park environmental auditing tools, this thesis builds a theoretical framework of dense urban park audit tool around five core dimensions. They are park surroundings and accessibility, activity area, facilities and amenities, safety, and aesthetics. The importance of environmental criteria was assessed through expert consensus to construct a framework of environmental attributes of parks in a dense urban context that affects physical activity. This process reflects the ability to construct systematic frameworks emphasized by Knowledge Science in responding to complex social problems.

6.4.3 Knowledge transformation

For knowledge transformation, the on-site validation and remote adaptation of dense urban park audit tool further expanded the use scenarios of the tool and enhanced its practicality, flexibility and generalizability. In particular, the use of Google Earth Pro images for virtual audits during remote adaptation reduces resource consumption and data collection costs, and provides a technical path for continuous monitoring and assessment of the urban environment. This “theory-data-adaptation” feedback path not only demonstrates the transformative potential of dense urban park audit tool as a “knowledge product”, but also provides a replicable case for the practice of Knowledge Science.

6.4.4 Knowledge application

The results of this thesis also respond positively to the social application of knowledge. In the context of rapid urban population growth and high prevalence of chronic diseases, how

to promote healthy lifestyles through urban space optimization is a typical interdisciplinary and cross-system problem. This thesis is driven by this complex reality problem, based on the methodology of Knowledge Science, realizes the effective interface between the theoretical knowledge of healthy urban design and its application in social practice, and reflects the social value of the knowledge of healthy urban design in the practical application to promote active living.

In summary, the development of dense urban park audit tool is not only a functional innovation of the traditional auditing tool, but also a successful practice in the whole process of knowledge generation, structural construction, knowledge transformation, and practical application of knowledge under the perspective of knowledge science. More importantly, the use of dense urban park audit tool to assess urban environments affecting physical activity to promote people's active lives and health and well-being provides a real-life case to support the goal of knowledge science, which is to “serve society with knowledge”.

References

1. Giles-Corti, B., et al., *Increasing walking: how important is distance to, attractiveness, and size of public open space?* American journal of preventive medicine, 2005. **28**(2): p. 169-176.
2. Carmona, M., *Contemporary public space, part two: Classification.* Journal of urban design, 2010. **15**(2): p. 157-173.
3. Jian, I.Y., J. Luo, and E.H. Chan, *Spatial justice in public open space planning: Accessibility and inclusivity.* Habitat International, 2020. **97**: p. 102122.
4. Koohsari, M.J., et al., *Public open space, physical activity, urban design and public health: Concepts, methods and research agenda.* Health & place, 2015. **33**: p. 75-82.
5. Azevedo, C., *Urban Public Parks.* Intergenerational Contact Zones: Place-based Strategies for Promoting Social Inclusion and Belonging, 2020: p. 88.
6. Carmona, M., *Public places urban spaces: The dimensions of urban design*. 2021: Routledge.
7. Acar, H., et al., *Analysis of activity, space and user relations in urban squares.* Indoor and Built Environment, 2021. **30**(9): p. 1466-1485.
8. Pourjafar, M. and A. Moradi, *Explaining design dimensions of ecological greenways.* Open Journal of Ecology, 2015. **5**(3): p. 66-79.
9. Vian, F.D., J.J.P. Izquierdo, and M.S. Martínez, *River-city recreational interaction: A classification of urban riverfront parks and walks.* Urban Forestry & Urban Greening, 2021. **59**: p. 127042.
10. Wang, H., et al., *Influence of urban green open space on residents' physical activity in China.* BMC public health, 2019. **19**: p. 1-12.
11. Konijnendijk, C.C., et al., *Benefits of urban parks.* A systematic review. A Report for IFPRA, Copenhagen & Alnarp, 2013. **70**.
12. Bedimo-Rung, A.L., A.J. Mowen, and D.A. Cohen, *The significance of parks to physical activity and public health: a conceptual model.* American journal of preventive medicine, 2005. **28**(2): p. 159-168.
13. Peters, K., B. Elands, and A. Buijs, *Social interactions in urban parks: Stimulating social cohesion?* Urban forestry & urban greening, 2010. **9**(2): p. 93-100.
14. Sarı, E.N. and S. Bayraktar, *The role of park size on ecosystem services in urban environment: a review.* Environmental Monitoring and Assessment, 2023. **195**(9): p. 1072.
15. Mexia, T., et al., *Ecosystem services: Urban parks under a magnifying glass.* Environmental research, 2018. **160**: p. 469-478.
16. Crompton, J.L. and S. Nicholls, *The impact of park views on property values.* Leisure Sciences, 2022. **44**(8): p. 1099-1111.
17. Menhas, R., et al., *Physical inactivity, non-communicable diseases and national fitness plan of China for physical activity.* Risk Manag. Healthc. Policy., 2021: p.

2319-2331.
18. Knobel, P., et al., *Development of the urban green space quality assessment tool (RECITAL).* Urban Forestry & Urban Greening, 2021. **57**: p. 126895.
19. Van Hecke, L., et al., *Public open space characteristics influencing adolescents' use and physical activity: A systematic literature review of qualitative and quantitative studies.* Health & place, 2018. **51**: p. 158-173.
20. Xu, M., et al., *Social inequalities of park accessibility in Shenzhen, China: The role of park quality, transport modes, and hierarchical socioeconomic characteristics.* Journal of Transport Geography, 2017. **62**: p. 38-50.
21. Rigolon, A., *A complex landscape of inequity in access to urban parks: A literature review.* Landscape and urban planning, 2016. **153**: p. 160-169.
22. Zhang, R., et al., *Associations between the physical environment and park-based physical activity: A systematic review.* Journal of Sport and Health Science, 2019. **8**(5): p. 412-421.
23. Flowers, E.P., et al., *Examining the features of parks that children visit during three stages of childhood.* International Journal of Environmental Research and Public Health, 2019. **16**(9).
24. Stewart, O.T., et al., *The association between park facilities and duration of physical activity during active park visits.* Journal of Urban Health, 2018. **95**: p. 869-880.
25. Veitch, J., et al., *What entices older adults to parks? Identification of park features that encourage park visitation, physical activity, and social interaction.* Landscape and Urban Planning, 2022. **217**: p. 104254.
26. Lapham, S.C., et al., *How important is perception of safety to park use? A four-city survey.* Urban Studies, 2016. **53**(12): p. 2624-2636.
27. Sherrington, C., et al., *Evidence on physical activity and falls prevention for people aged 65+ years: systematic review to inform the WHO guidelines on physical activity and sedentary behaviour.* Int J Behav Nutr Phys Act, 2020. **17**(1): p. 144.
28. World Health Organization, *WHO Guidelines on Physical Activity and Sedentary Behaviour*, in *WHO Guidelines on Physical Activity and Sedentary Behaviour*. 2020: Geneva.
29. Schoenfeld, B.J., D. Ogborn, and J.W. Krieger, *Effects of resistance training frequency on measures of muscle hypertrophy: a systematic review and meta-analysis.* Sports medicine, 2016. **46**(11): p. 1689-1697.
30. Jakicic, J.M., et al., *Association between bout duration of physical activity and health: systematic review.* Medicine and science in sports and exercise, 2019. **51**(6): p. 1213.
31. Kemel, P.N., J.E. Porter, and N. Coombs, *Improving youth physical, mental and social health through physical activity: a systematic literature review.* Health Promotion Journal of Australia, 2022. **33**(3): p. 590-601.
32. Boakye-Dankwa, E., et al., *Walking behaviour and patterns of perceived access to neighbourhood destinations in older adults from a low-density (Brisbane, Australia) and an ultra-dense city (Hong Kong, China).* Cities, 2019. **84**: p. 23-33.
33. Kraus, W.E., et al., *Physical activity, all-cause and cardiovascular mortality, and cardiovascular disease.* Medicine and science in sports and exercise, 2019. **51**(6): p.

1270.
34. Biddle, S., *Physical activity and mental health: evidence is growing.* World Psychiatry, 2016. **15**(2): p. 176.
35. Biddle, S.J., et al., *Physical activity and mental health in children and adolescents: An updated review of reviews and an analysis of causality.* Psychology of sport and exercise, 2019. **42**: p. 146-155.
36. da Silva Rodrigues, S.L., et al., *Physical exercise as a non-pharmacological strategy for reducing behavioral and psychological symptoms in elderly with mild cognitive impairment and dementia: a systematic review of randomized clinical trials.* Arquivos de Neuro-Psiquiatria, 2021. **79**(12): p. 1129-1137.
37. World Health Organization, *Global action plan on physical activity 2018-2030: more active people for a healthier world*. 2019: World Health Organization.
38. Lindsay Smith, G., et al., *The association between social support and physical activity in older adults: a systematic review.* International journal of behavioral nutrition and physical activity, 2017. **14**: p. 1-21.
39. Luo, Y., et al., *Developing and testing an audit tool for activity-friendly parks in dense urban areas of Asia.* Cities & Health, 2024: p. 1-13.
40. Ghosh-Dastidar, M., et al., *An audit tool for longitudinal assessment of the health-related characteristics of urban neighborhoods: Implementation methods and reliability results.* BMC Public Health., 2020. **20**(1): p. 1519.
41. Jones, L., *Resilience isn't the same for all: Comparing subjective and objective approaches to resilience measurement.* Wiley Interdisciplinary Reviews: Climate Change, 2019. **10**(1): p. e552.
42. Luo, Y., et al., *Redesigning urban parks for active living in dense urban areas: a remote audit approach.* International Journal of Environmental Health Research, 2025: p. 1-11.
43. García-Pérez, S., J. Sierra-Pérez, and J. Boschmonart-Rives, *Environmental assessment at the urban level combining LCA-GIS methodologies: A case study of energy retrofits in the Barcelona metropolitan area.* Building and Environment, 2018. **134**: p. 191-204.
44. Boffi, M. and N. Rainisio, *To be there, or not to be. designing subjective urban experiences.* Urban design and representation: a multidisciplinary and multisensory approach, 2017: p. 37-53.
45. Noel, C., C. Vanroelen, and S. Gadeyne, *Qualitative research about public health risk perceptions on ambient air pollution. A review study.* SSM-population health, 2021. **15**: p. 100879.
46. Gustat, J., C.E. Anderson, and S.J. Slater, *Development and testing of a brief play space audit tool.* Journal of Physical Activity and Health, 2020. **17**(1): p. 13-20.
47. Ka Yiu, L., D. Macfarlane, and E. Cerin, *Objective Evaluation of Recreational Facilities: Development and Reliability of the Recreational Facility Audit Tool.* Journal of Park & Recreation Administration, 2013. **31**(4): p. 92-109.
48. Edwards, N., et al., *Development of a public open space desktop auditing tool (POSDAT): a remote sensing approach.* Applied Geography, 2013. **38**: p. 22-30.

49. Müller, C., et al., *Development and reliability testing of an audit toolbox for the assessment of the physical activity friendliness of urban and rural environments in Germany.* Frontiers in Public Health, 2023. **11**.
50. Lee, H.-S., *Developing and testing the senior park environment assessment in Korea (SPEAK) audit tool.* Landscape and Urban Planning, 2022. **227**: p. 104545.
51. Lee, I.M., et al., *Effect of physical inactivity on major non-communicable diseases worldwide: An analysis of burden of disease and life expectancy.* Lancet., 2012. **380**(9838): p. 219-29.
52. World Health Organization. *Non-communicable diseases.* 2022; Available from: https://www.who.int/news-room/fact-sheets/detail/noncommunicable-diseases.
53. Sallis, J.F., et al., *An international physical activity and public health research agenda to inform coronavirus disease-2019 policies and practices.* J. Sport. Health. Sci., 2020. **9**(4): p. 328-334.
54. Laddu, D., A.E. Paluch, and M.J. LaMonte, *The role of the built environment in promoting movement and physical activity across the lifespan: Implications for public health.* Prog Cardiovasc Dis., 2021. **64**: p. 33-40.
55. Sallis, J.F., N. Owen, and E. Fisher, *Ecological models of health behavior.* Health behavior: Theory, research, and practice, 2015. **5**(43-64).
56. Fazeli Dehkordi, Z.S., S.M. Khatami, and E. Ranjbar, *The Associations Between Urban Form and Major Non-communicable Diseases: A Systematic Review.* Journal of Urban Health, 2022. **99**(5): p. 941-958.
57. Prüss-Üstün, A., et al., *Preventing disease through healthy environments: a global assessment of the burden of disease from environmental risks*. The Japanese version is published by the National Institute of Public Health, Japan ed. 2016, Geneva: World Health Organization. 147.
58. Motomura, M., et al., *Associations of public open space attributes with active and sedentary behaviors in dense urban areas: A systematic review of observational studies.* Health & place, 2022. **75**: p. 102816.
59. Sugiyama, T., et al., *Advantages of public green spaces in enhancing population health.* Landscape and Urban Planning, 2018. **178**: p. 12-17.
60. Day, K., et al., *The Irvine–Minnesota inventory to measure built environments: development.* American journal of preventive medicine, 2006. **30**(2): p. 144-152.
61. Bedimo-Rung, A.L., et al., *Development of a direct observation instrument to measure environmental characteristics of parks for physical activity.* Journal of Physical Activity and Health, 2006. **3**(s1): p. S176-S189.
62. Saelens, B.E., et al., *Measuring physical environments of parks and playgrounds: EAPRS instrument development and inter-rater reliability.* Journal of Physical Activity and Health, 2006. **3**(s1): p. S190-S207.
63. Philip J. Troped, E.K.C., Maren S. Fragala, Steven J. Melly, Hope H. Hasbrouck, Steven L. Gortmaker, and Ross C. Brownson, *Development and Reliability and Validity Testing of an Audit Tool for Trail/Path Characteristics: The Path Environment Audit Tool (PEAT).* Journal of Physical Activity and Health, 2006.
64. Kaczynski, A.T., S.A. Wilhelm Stanis, and G.M. Besenyi, *Development and Testing of*

a Community Stakeholder Park Audit Tool. American Journal of Preventive Medicine, 2012. **42**(3): p. 242-249.
65. Ouyang, X., et al., *Spatial interaction between urbanization and ecosystem services in Chinese urban agglomerations.* Land Use Policy, 2021. **109**: p. 105587.
66. Su, H., H. Wei, and J. Zhao, *Density effect and optimum density of the urban population in China.* Urban Studies, 2017. **54**(7): p. 1760-1777.
67. United Nations. *World urbanization prospects: The 2018 revision*. Online Edition [Online Edition] 2018; Available from: https://population.un.org/wup/Download/.
68. Thilakaratne, R. *Designing liveable urban open spaces in high density cities*. in *IOP Conference Series: Earth and Environmental Science*. 2019. IOP Publishing.
69. Yu, P., et al., *Capturing open space fragmentation in high–density cities: Towards sustainable open space planning.* Applied Geography, 2023. **154**: p. 102927.
70. Cerin, E., et al., *Objectively-assessed neighbourhood destination accessibility and physical activity in adults from 10 countries: An analysis of moderators and perceptions as mediators.* Social Science & Medicine, 2018. **211**: p. 282-293.
71. Cerin, E., et al., *Sharing good NEWS across the world: Developing comparable scores across 12 countries for the Neighborhood Environment Walkability Scale (NEWS).* BMC Public Health, 2013. **13**(1): p. 1-14.
72. Bird, M.E., et al., *A reliability assessment of a direct-observation park evaluation tool: the parks, activity and recreation among kids (PARK) tool.* BMC Public Health, 2015. **15**: p. 906.
73. Liberati, A., et al., *The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration.* Annals of internal medicine, 2009. **151**(4): p. W-65-W-94.
74. Cavnar, M.M., et al., *Evaluating the Quality of Recreation Facilities: Development of an Assessment Tool.* Journal of Park & Recreation Administration, 2004. **22**(1): p. 96-114.
75. Lee, R.E., et al., *The Physical Activity Resource Assessment (PARA) instrument: evaluating features, amenities and incivilities of physical activity resources in urban neighborhoods.* Int J Behav Nutr Phys Act, 2005. **2**: p. 13.
76. McKenzie, T.L., et al., *System for Observing Play and Recreation in Communities (SOPARC): reliability and feasibility measures.* Journal of Physical Activity and Health, 2006. **3**(s1): p. S208-S222.
77. Crawford, D., et al., *Do features of public open spaces vary according to neighbourhood socio-economic status?* Health & Place, 2008. **14**(4): p. 889-893.
78. Badland, H.M., et al., *Examining Public Open Spaces by Neighborhood-Level Walkability and Deprivation.* Journal of Physical Activity & Health, 2010. **7**(6): p. 818-824.
79. Gidlow, C.J., N.J. Ellis, and S. Bostock, *Development of the Neighbourhood Green Space Tool (NGST).* Landscape and Urban Planning, 2012. **106**(4): p. 347-358.
80. Veitch, J., et al., *Do features of public open spaces vary between urban and rural areas?* Preventive Medicine, 2013. **56**(2): p. 107-111.
81. Kaczynski, A.T., et al., *ParkIndex: Development of a standardized metric of park*

access for research and planning. Preventive Medicine, 2016. **87**: p. 110-114.
82. Shuvo, F.K., X. Feng, and T. Astell-Burt, *Urban green space quality and older adult recreation: an international comparison.* Cities and Health, 2021. **5**(3): p. 329-349.
83. Medina, C., et al., *Development and Validation of the Mexican Public Open Spaces Tool (MexPOS).* International Journal of Environmental Research and Public Health, 2022. **19**(13).
84. Dempsey, N., C. Brown, and G. Bramley, *The key to sustainable urban development in UK cities? The influence of density on social sustainability.* Progress in planning, 2012. **77**(3): p. 89-141.
85. Labbé, D., U. Lachapelle, and É. Pelletier, *Perception of park access and park use amongst youth in Hanoi: How cultural and local context matters.* Landscape and urban planning, 2019. **189**: p. 156-165.
86. Day, K., et al., *The Irvine-Minnesota inventory to measure built environments: development.* Am J Prev Med, 2006. **30**(2): p. 144-52.
87. Boarnet, M.G., et al., *The Irvine-Minnesota inventory to measure built environments: reliability tests.* Am J Prev Med, 2006. **30**(2): p. 153-159.
88. Gidlow, C., et al., *Development of the natural environment scoring tool (NEST).* Urban Forestry & Urban Greening, 2018. **29**: p. 322-333.
89. Saelens, B.E., et al., *Measuring Physical Environments of Parks and Playgrounds: EAPRS Instrument Development and Inter-Rater Reliability.* J Phys Act Health, 2006. **3**(s1): p. S190-S207.
90. Cunningham, G.O., et al., *Developing a reliable senior walking environmental assessment tool.* American journal of preventive medicine, 2005. **29**(3): p. 215-217.
91. Giles-Corti, B., et al., *Increasing walking: How important is distance to, attractiveness, and size of public open space?* Am J Prev Med, 2005. **28**(2 Suppl 2): p. 169-76.
92. Lee, H.S., *Developing and testing the senior park environment assessment in Korea (SPEAK) audit tool.* Landscape and Urban Planning, 2022. **227**.
93. Ariane L. Bedimo-Rung, J.G., Bradley J. Tompkins, Janet Rice, and Jessica Thomson, *Development of a Direct Observation Instrument to Measure Environmental Characteristics of Parks for Physical Activity.* Journal of Physical Activity and Health, 2006.
94. Crawford, D., et al., *Do features of public open spaces vary according to neighbourhood socio-economic status?* Health Place, 2008. **14**(4): p. 889-93.
95. Ariane L. Bedimo-Rung, J.G., Bradley J. Tompkins, Janet Rice, and Jessica Thomson, *Development of a direct observation instrument to measure environmental characteristics of parks for physical activity.* Journal of Physical Activity and Health, 2006. **3**(s1): p. S176-S189.
96. Cavnar, M.M., et al., *Evaluating the Quality of Recreation Facilities: Development of an Assessment Tool.* Journal of Park & Recreation Administration, 2004. **22**(1).
97. Bird, M.E., et al., *A reliability assessment of a direct-observation park evaluation tool: the Parks, activity and recreation among kids (PARK) tool.* BMC public health, 2015. **15**: p. 1-11.

98. Day, K., et al., *The Irvine-Minnesota inventory to measure built environments: Development.* American Journal of Preventive Medicine, 2006. **30**(2): p. 144-152.
99. Pikora, T.J., et al., *Developing a reliable audit instrument to measure the physical environment for physical activity.* American Journal of Preventive Medicine, 2002. **23**(3): p. 187-194.
100. Michael, Y.L., et al., *Revising the senior walking environmental assessment tool.* Preventive Medicine, 2009. **48**(3): p. 247-249.
101. Dalkey, N. and O. Helmer, *An experimental application of the Delphi method to the use of experts.* Management Science, 1963. **9**(3): p. 458-467.
102. Ishikawa, A., et al., *The max-min Delphi method and fuzzy Delphi method via fuzzy integration.* Fuzzy sets and systems, 1993. **55**(3): p. 241-253.
103. Ocampo, L., et al., *Sustainable ecotourism indicators with fuzzy Delphi method–A Philippine perspective.* Ecological Indicators, 2018. **93**: p. 874-888.
104. Wang, Y. and G.-T. Yeo, *Intermodal route selection for cargo transportation from Korea to Central Asia by adopting Fuzzy Delphi and Fuzzy ELECTRE I methods.* Maritime Policy & Management, 2018. **45**(1): p. 3-18.
105. Li, S.-J., et al., *Exploring Strategies for Improving Green Open Spaces in Old Downtown Residential Communities from the Perspective of Public Health to Enhance the Health and Well-Being of the Aged.* Journal of Healthcare Engineering, 2021. **2021**: p. 1-20.
106. Zhu, B.-W., et al., *A hybrid multiple-attribute decision-making model for evaluating the esthetic expression of environmental design schemes.* Sage Open, 2022. **12**(2): p. 21582440221087268.
107. Jeng, T.-B., *Fuzzy assessment model for maturity of software organization in improving its staff's capability*, in *National Taiwan University of Science and Technology*. 2001, National Taiwan University of Science and Technology, Taipei, Taiwan. p. 131.
108. Statistics Bureau of Japan. *What is a Densely Inhabited District?* 2023; Available from: Available link: https://www.stat.go.jp/english/data/chiri/did/1-1.html.
109. Statistics of Japan. *Population Census*. 2022; Available from: Available link: https://www.e-stat.go.jp/en/stat-search/files?tclass=000001125102&cycle=0.
110. Beal, B., et al., *Skateboarding, community and urban politics: Shifting practices and challenges.* International Journal of Sport Policy and Politics, 2017. **9**(1): p. 11-23.
111. Abadi, M.G. and D.S. Hurwitz, *Bicyclist's perceived level of comfort in dense urban environments: How do ambient traffic, engineering treatments, and bicyclist characteristics relate?* Sustainable Cities and Society, 2018. **40**: p. 101-109.
112. Bird, M.E., et al., *A reliability assessment of a direct-observation park evaluation tool: The parks, activity and recreation among kids (PARK) tool.* BMC Public Health, 2015. **15**: p. 906 ().
113. Boarnet, M.G., et al., *The Irvine-Minnesota inventory to measure built environments: Reliability tests.* American Journal of Preventive Medicine, 2006. **30**(2): p. 153-159.
114. Tokyo Metropolitan Government. *Tokyo Metropolitan Population (Estimates): Monthly*. Statistics of Tokyo 2024; Available from:

https://www.toukei.metro.tokyo.lg.jp/jsuikei/js-index.htm.
115. Australian Bureau of Statistics, *Regional population. ABS.(2022-23)*. 2023, Australian Bureau of Statistics: Canberra, Australian.
116. Statistics Bureau of Japan. *What is a Densely Inhabited District?* 2024; Available from: Available link: https://www.stat.go.jp/english/data/chiri/did/1-1.html.
117. Tokyo Metropolitan Government, *Tokyo Metropoliten Parks Guide 2023-2024*, in *Bureau of Construction*, T.M.G.B.o.G. Affairs, Editor. 2024, Bureau of Construction: Tokyo, Japan.
118. Pinto, L., C.S. Ferreira, and P. Pereira, *Environmental and socioeconomic factors influencing the use of urban green spaces in Coimbra (Portugal).* Science of the Total Environment, 2021. **792**: p. 148293.
119. Nakaya, T., et al., *Associations of all-cause mortality with census-based neighbourhood deprivation and population density in Japan: a multilevel survival analysis.* PloS one, 2014. **9**(6): p. e97802.
120. Wan, T., et al., *Kappa coefficient: a popular measure of rater agreement.* Shanghai archives of psychiatry, 2015. **27**(1): p. 62.
121. Landis, J.R. and G.G. Koch, *The measurement of observer agreement for categorical data.* biometrics, 1977. **33**(1): p. 159-174.
122. Kaczynski, A.T., S.A.W. Stanis, and G.M. Besenyi, *Development and testing of a community stakeholder park audit tool.* American journal of preventive medicine, 2012. **42**(3): p. 242-249.
123. Phillips, C.B., et al., *Online versus in-person comparison of Microscale Audit of Pedestrian Streetscapes (MAPS) assessments: reliability of alternate methods.* International journal of health geographics, 2017. **16**: p. 1-13.
124. Aghaabbasi, M., et al., *Addressing issues in the use of Google tools for assessing pedestrian built environments.* Journal of Transport Geography, 2018. **73**: p. 185-198.
125. Rzotkiewicz, A., et al., *Systematic review of the use of Google Street View in health research: Major themes, strengths, weaknesses and possibilities for future research.* Health & place, 2018. **52**: p. 240-246.
126. Dai, S., et al., *Street view imagery-based built environment auditing tools: a systematic review.* International Journal of Geographical Information Science, 2024: p. 1-22.
127. Mygind, L., et al., *Public open space desktop auditing tool—Establishing appropriateness for use in Australian regional and urban settings.* Urban Forestry & Urban Greening, 2016. **20**: p. 65-70.
128. Koohsari, M.J., T. Nakaya, and K. Oka, *Activity-friendly built environments in a super-aged society, Japan: current challenges and toward a research agenda.* International journal of environmental research and public health, 2018. **15**(9): p. 2054.
129. Pilia, M.V. and F.R. Fonseca, *The influence of the urban model on civic involvement and public time. A study applied to the commuting population of the Greater Metropolitan Area of San José, Costa Rica.* Cities, 2024. **148**: p. 104849.
130. Tokyo Metropolitan Government, *Tokyo Metropolitan Population (Estimates):*

Monthly, in *Statistics of Tokyo*, B.o.G.A. Statistics Division, Editor. 2024, Statistics Division, Bureau of General Affairs, : Tokyo, Japan p. 1.
131. Liang, J., J. Gong, and W. Li, *Applications and impacts of Google Earth: A decadal review (2006–2016).* ISPRS Journal of Photogrammetry and Remote Sensing, 2018. **146**: p. 91-107.
132. Taylor, B.T., et al., *Measuring the quality of public open space using Google Earth.* American journal of preventive medicine, 2011. **40**(2): p. 105-112.
133. Sheppard, S.R. and P. Cizek, *The ethics of Google Earth: Crossing thresholds from spatial data to landscape visualisation.* Journal of environmental management, 2009. **90**(6): p. 2102-2117.
134. Griew, P., et al., *Developing and testing a street audit tool using Google Street View to measure environmental supportiveness for physical activity.* International Journal of Behavioral Nutrition and Physical Activity, 2013. **10**: p. 1-7.
135. Landis, J.R. and G.G. Koch, *The measurement of observer agreement for categorical data.* Biometrics, 1977. **33**(1): p. 159-74.
136. Andersen, O.K., et al., *Adapting the SPOTLIGHT Virtual Audit Tool to assess food and activity environments relevant for adolescents: a validity and reliability study.* International journal of health geographics, 2021. **20**: p. 1-14.
137. Koo, T.K. and M.Y. Li, *A guideline of selecting and reporting intraclass correlation coefficients for reliability research.* Journal of chiropractic medicine, 2016. **15**(2): p. 155-163.
138. Gullón, P., et al., *Assessing walking and cycling environments in the streets of Madrid: comparing on-field and virtual audits.* Journal of urban health, 2015. **92**: p. 923-939.
139. Charreire, H., et al., *Using remote sensing to define environmental characteristics related to physical activity and dietary behaviours: a systematic review (the SPOTLIGHT project).* Health & place, 2014. **25**: p. 1-9.

Appendix

Appendix 1. Questionnaire on park attributes supporting physical activity in dense urban areas

The aim of this questionnaire is to evaluate the importance of attributes in (re)designing parks to support residents' physical activity in the context of dense urban areas. Please evaluate the importance of each factor with the 5-point Likert scale.

1	2	3	4	5
Very unimportant	Unimportant	Neutral	Important	Very important

* 1. **Park surrounding and accessibility**

(Please assess the importance of each criterion in supporting residents' park-based physical activity)

	Very unimportant	Unimportant	Neutral	Important	Very important
1. Number of entrance point	○	○	○	○	○
2. Traffic safety	○	○	○	○	○
3. Sidewalks or bike paths on any roads bordering the park	○	○	○	○	○
4. Access to public transport station	○	○	○	○	○
5. Available parking lot	○	○	○	○	○

* 2. **Activity areas in park**

(Please assess the importance of each criterion in supporting residents' park-based physical activity)

	Very unimportant	Unimportant	Neutral	Important	Very important
6. Sport court	◯	◯	◯	◯	◯
7. Playground	◯	◯	◯	◯	◯
8. Running and cycling track	◯	◯	◯	◯	◯
9. Fitness area	◯	◯	◯	◯	◯
10. Swimming pool	◯	◯	◯	◯	◯
11. Skateboard area	◯	◯	◯	◯	◯
12. Skating rink	◯	◯	◯	◯	◯
13. Water sport	◯	◯	◯	◯	◯
14. Open/Green space	◯	◯	◯	◯	◯

* 3. **Park facility and amenity**

(Please assess the importance of each criterion in supporting residents' park-based physical activity)

	Very unimportant	Unimportant	Neutral	Important	Very important
15. Path	◯	◯	◯	◯	◯
16. Public toilet	◯	◯	◯	◯	◯
17. Shelter and pavilion	◯	◯	◯	◯	◯
18. Drinking fountain	◯	◯	◯	◯	◯
19. Vending machine	◯	◯	◯	◯	◯
20. Bench	◯	◯	◯	◯	◯
21. Picnic table	◯	◯	◯	◯	◯
22. Trash can	◯	◯	◯	◯	◯

* 4. **Aesthetic**

(Please assess the importance of each criterion in supporting residents' park-based physical activity)

	Very unimportant	Unimportant	Neutral	Important	Very important
23. Water feature	◯	◯	◯	◯	◯
24. Vegetation and landscape	◯	◯	◯	◯	◯
25. Public art	◯	◯	◯	◯	◯
26. Graffiti	◯	◯	◯	◯	◯
27. Litter	◯	◯	◯	◯	◯

* 5. **Park safety**

(Please assess the importance of each criterion in supporting residents' park-based physical activity)

	Very unimportant	Unimportant	Neutral	Important	Very important
28. Lighting	◯	◯	◯	◯	◯
29. Surveillance equipment	◯	◯	◯	◯	◯
30. Emergency device	◯	◯	◯	◯	◯
31. Warning sign	◯	◯	◯	◯	◯

Final note

Considering the difference in 'semantic thinking' of the importance of each person, we list 5 semantic scales. Please select an interval (1-25) to represent your 'semantic thinking' of importance on the following semantic scales.

The choice of semantic intervals is completely free and unconstrained, and the semantic intervals can be wide or narrow, overlapping or non-overlapping.

Sample:

	Semantic interval (Min)	Semantic interval (Max)
1. Very unimportant	1	4
2. Unimportant	6	10
3. Neutral	12	17
4. Important	17	19
5. Very important	20	25

* 6. Please select an interval (1-25) to represent your 'semantic thinking' of importance on the following semantic scales.

The choice of semantic intervals is completely free and unconstrained, and the semantic intervals can be wide or narrow, overlapping or non-overlapping.

	Semantic interval (Min)	Semantic interval (Max)
1. Very unimportant		
2. Unimportant		
3. Neutral		
4. Important		
5. Very important		

Thank you very much for your time and support. If you have questions about the survey, you may contact me by email: yufengluo@jaist.ac.jp.

Appendix 2. The steps of fuzzy Delphi method

Step 1. Counting the conservative value and optimistic value.

Counting the interval value of each evaluation criterion by experts in fuzzy Delphi questionnaires. The "minimum value" among the interval value represents the expert's conservative estimate of the quantitative score of criteria, that is the conservative value (***C***), while the "maximum value" among the interval values represents the optimistic estimate of the quantitative score of criteria, the optimistic value (***O***).

Step 2. Eliminate extreme values outside of the double standard deviation.

Counting the minimum value and maximum value of each criterion and eliminate extreme values outside of the double standard deviation. Then, calculate the remaining minimum value, maximum value, and geometric mean of the conservative value and the optimistic value.

Step 3. Check whether the expert opinions are consistent based on the grey zone verification method.

Establish the triangular fuzzy number $\boldsymbol{C_L^i, C_M^i, C_U^i}$ of the $\boldsymbol{C}_i$ and $\boldsymbol{O_L^i, O_M^i, O_U^i}$ of the $\boldsymbol{O}_i$ calculated on the basis on ***Step 2.*** Shown as Figure 1, the interval between the value of $\boldsymbol{C_U^i}$ and $\boldsymbol{O_L^i}$ refers to the verification value of $\boldsymbol{M_i - Z_i}$ for the Grey Zone, where $\boldsymbol{M_i = O_M^i - C_M^i}$, $\boldsymbol{Z_i = C_U^i - O_L^i}$. In the case that the value of $\boldsymbol{C_U^i}$ is larger than $\boldsymbol{O_L^i}$, or $\boldsymbol{M_i - Z_i}$ is bigger than 0, it means that the expert opinions tend to be identical, and convergence is reached for the evaluation criterion. When $\boldsymbol{M_i - Z_i}$ is negative, it means that the expert opinions are not in agreement with each other, and no convergence is reached for the evaluation criterion. At this

point, the second turn questionnaire can be used for the evaluation criterion for which convergence has not yet been reached.

Step 4. Calculate the consensus value G_i of the expert, and identify the reasonable threshold. The intersection node of the two lines of the C_U^i and O_L^i refers to the consensus value G_i of the expert, which presents an important basis for the identification of the threshold. In the meantime, the higher the value of G_i, the higher the consensus value of the expert. In other words, the higher the importance of the evaluation criterion.

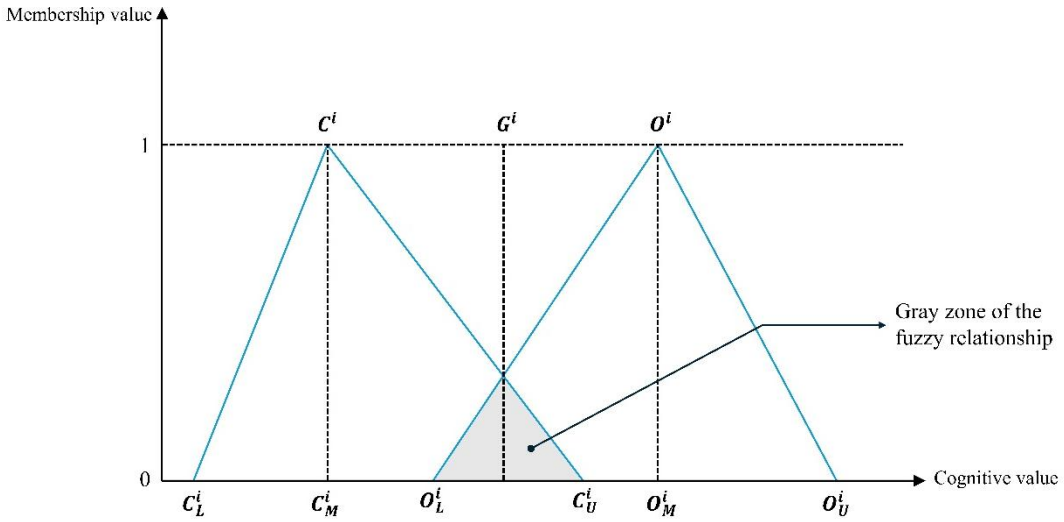

Figure 1. Triangular fuzzy numbers formed using the fuzzy Delphi method.

Appendix 3. A dense urban park audit tool

Introduction

The dense urban park audit tool was developed to audit park attributes that support physical activity in dense urban areas in Asia. Please follow these requirements when using this audit tool:

a). Before starting the on-site audit, the auditor should fully review the audit tool.

b). Walk around both the park's perimeter and interior, photographing park attributes relevant to the audit items.

c). Record the total time spent auditing, including time spent observing the park.

d). Finally, ensure that all questions are answered, and record the end time.

Section 1. Basic information

Park name: _____ Auditor name: _____

Audit date: _____(Year/Month/Day) Temperature: _____

Weather conditions: Start time: _____

_____

Section 2. Surroundings and accessibility

Entrance point and signage

1. How many entrance points are there for smooth access to the park?

   0. 1-2 1. 3-5 2. > 6 (or park boundary is open)

2. Are there any signs showing the location or directions to the park?

   0. No 1. Yes

3. Is there any park information at the entrance points? (e.g., park name, maps, opening hours, rules and prohibitions)

0. No 1. Yes

4. Are the entrance points attractive to residents?

0. None 1. Some 2. A lot

Comments:

Traffic safety

5. Are there any crosswalks on the roads leading to the park?

0. No 1. Yes

6. Are there any traffic lights at the crosswalks?

0. No 1. Yes

7. Are there any speed limit signs on the roads leading to the park?

0. No 1. Yes

8. Is the traffic situation around the park generally safe for residents?

0. None 1. Some 2. A lot

Comments:

Road bordering the park

9. Are there sidewalks/bike lanes on the roads bordering the park? (If not, please skip to 12)

0. No 1. Yes

10. Is the width of the sidewalk/bike lane suitable for walking/cycling?

0. No 1. Yes

11. Are there any obstacles on the sidewalk/bike lane that prevent movement *

0. No 1. Yes

Comments:

Public transport station

12. Are there any public transport stations close to the park? (Please use the electronic map to search for all public stations within 15-min walk to the park.) (If not, please skip to 14)

0. No 1. Yes

13. How long does it take to walk or cycle from the nearest public transport station to the nearest park entrance (min)? *

0. ≤ 5 1. 6-10 2.11-15

Comments:

5. Parking lot

14. Are there any parking lots specifically provided by the park? (If Yes, how many parking spaces are there?)

0. No 1. Yes, _____(n)

15. Are there any bicycle racks specifically provided by the park? (If Yes, how many bicycle racks are there?)

0. No 1. Yes, _____(n)

16. Is the parking free?

0. No 1. Yes

17. Is it convenient to park? (Consider the entrance and exit signs, and parking management)

0. None 1. Some 2. A lot

Comments:

Section 3. Activity areas

Sport court

18. What types of sports courts are in the park?

□ Basketball court	□ Soccer court	□ Baseball court
□ Volleyball court	□ Badminton court	□ Handball court
□ Tennis court	□ Table tennis court	□ Softball court

Other_____

Court 1. _____ Court 2. _____ Court 3. _____

19. Are the sports courts usable?

0. No 1. Yes 0. No 1. Yes 0. No 1. Yes

20. Are the sports courts free to use?

0. No 1. Yes 0. No 1. Yes 0. No 1. Yes

21. Are there any guidance or warning signs for sports court users?

0. No 1. Yes 0. No 1. Yes 0. No 1. Yes

22. Are there any benches for resting?

0. No 1. Yes 0. No 1. Yes 0. No 1. Yes

23. Are there any shade areas or shelters near the sports courts?

0. No 1. Yes 0. No 1. Yes 0. No 1. Yes

24. Are the sports courts fenced?

0. No 1. Yes 0. No 1. Yes 0. No 1. Yes

25. Are the sports courts in good condition?

0. Not 1. Some 2. A lot 0. Not 1. Some 2. A lot 0. Not 1. Some 2. A lot

Comments:

Playground

26. Are there any playgrounds in the park? (If not, please skip to 31)

0. No 1. Yes

27. Are the playgrounds usable? (If people are using it, it is usable. If no one is using it, consider whether it is forbidden or abandoned.)

0. No 1. Yes

28. How many types of playgrounds equipment are present? (e.g., swings, seesaws, slides, trampolines, carousels, rock climbing, etc.)

0. ≤5 1. 6-9 2. ≥ 10

29. Are there any guidance or warning signs for playground users?

0. No 1. Yes

30. Are the playgrounds in good condition? (Consider the cleanliness, management and safety)

0. None 1. Some 2. A lot

Comments:

Running track

31. Are there any tracks specifically for running? (If not, please skip to 34)

0. No 1. Yes

32. Are there any obstacles on the running tracks that prevent movement? *

0. None 1. Some 2. A lot

33. Are the running tracks in good condition? (Consider the cleanliness, surface and management)

0. None 1. Some 2. A lot

Comments:

Fitness area

34. Are there any fitness areas in the park? (If not, please skip to 37)

0. No 1. Yes

35. Are there any guidance or warning signs for fitness area users?

0. No 1. Yes

36. Are the fitness areas in good condition? (Consider the cleanliness, management and safety)

0. None 1. Some 2. A lot

Comments:

Open/Green space

37. Are there any open/green spaces in the park where people can freely access and conduct activities? (If not, please skip to 41)

0. No 1. Yes

38. Are the surfaces of the open/green spaces flat?

0. None 1. Some 2. A lot

39. Are there any guidance or warning signs for open/green spaces users?

0. No 1. Yes

40. Are the open/green spaces in good condition? (Consider the cleanliness, safety, and maintenance)

0. None 1. Some 2. A lot

Comments:

Section 4. Facilities and amenities

Path

41. Are there any walking paths in the park? (If not, please skip to 46)

0. No 1. Yes

42. Are the paths appropriately wide for walking?

0. No 1. Yes

43. Are there any obstacles on the path? *

0. None 1. Some 2. A lot

44. Are the paths sloping? *

0. None 1. Some 2. A lot

45. Are the paths in good condition? (Consider the cleanliness, maintenance and surface)

0. None 1. Some 2. A lot

Comments:

Public toilet

46. Are there any public toilets in the park? (If not, please skip to 49)

0. No 1. Yes

47. Are there any amenities offered in the toilets? (e.g., hand soap, hand towels, mirrors, toilet paper, etc.)

0. None 1. Some 2. A lot

48. Are the public toilets in good condition? (Consider the cleanliness, maintenance and safety)

0. None 1. Some 2. A lot

Comments:

Shelter and pavilion

49. Are there any shelters and pavilions in the park? (If not, please skip to 52)

0. No 1. Yes

50. Are there any benches for resting under the shelters and pavilions?

0. No 1. Yes

51. Are the shelters and pavilions in good condition? (Consider the cleanliness, safety and maintenance.)

0. None 1. Some 2. A lot

Comments:

Drinking fountain

52. Are there any drinking fountains in the park? (If not, please skip to 54)

0. No 1. Yes

53. Are the drinking fountains usable? (If people are using them, they are usable. If no one is using them, consider whether they are vacated, destroyed, or abandoned)

0. No 1. Yes

Comments:

Bench

54. Are there any benches for resting in the park? (Exclude benches in themed areas such as sports courts or playgrounds) (If not, please skip to 58)

0. No 1. Yes

55. Are there any tree shades or coverings over the benches?

0. None 1. Some 2. A lot

56. Are there any pleasant views while resting on the benches?

0. None 1. Some 2. A lot

57. Are the benches in good condition? (Consider the cleanliness, maintenance and comfort.)

0. None 1. Some 2. A lot

Comments:

Picnic table

58. Are there any picnic tables in the park? (If not, please skip to 61)

0. No 1. Yes

59. Are there any tree shades or coverings over the picnic tables?

0. None 1. Some 2. A lot

60. Are the picnic tables in good condition? (Consider the cleanliness, maintenance and comfort.)

0. None 1. Some 2. A lot

Comments:

Trash can

61. Are there any trash cans in the park? (If not, please skip to 64)

0. No 1. Yes

62. Are the trash cans easy to find in the park?

0. None 1. Some 2. A lot

63. Are the trash cans in good condition? (Consider the cleanliness, maintenance, and odor)

0. None 1. Some 2. A lot

Comments:

Section 5. Aesthetics

Vegetation and landscape

64. How many species of vegetation can you identify in the park? (Including flowers and plants)

0. <10 1. 11-30 2. >30

65. Has any vegetation and landscape in the park been uprooted or damaged? *

0. None 1. Some 2. A lot

66. Are the vegetation and landscape in good condition? (Consider the management, mowing, and design)

0. None 1. Some 2. A lot

Comments:

Graffiti

67. Are there unauthorised graffiti in the park? *

0. No 1. Yes

Comments:

Litter

68. Is there any litter in the park? (Do not consider litter inside the trash cans). *

0. None 1. Some 2. A lot

Comments:

Section 6. Safety

Lighting

69. Is the lighting in the park adequate? (e.g., lighting in the most parts of the park)

0. None 1. Some 2. A lot

Comments:

Surveillance equipment

70. Is there surveillance equipment in the park?

0. No 1. Yes

Comments:

Emergency device

71. Are there any emergency devices in the park? (e.g., fire alarms, fire hydrants, Automated External Defibrillators (AED), or health service stations) (If not, please skip to 73)

0. No 1. Yes

72. Are the locations of emergency equipment marked on the park map?

0. No 1. Yes

Comments:

Warning sign

73. Are there any warning signs in the park? (e.g., no swimming, no smoking, and dogs prohibited). (If not, please skip it)

0. No 1. Yes

74. Are these warning signs clear?

0. None 1. Some 2. A lot

Comments:

This ends the audit questionnaire. Thank you.

End time: _____ Total audit time: _____(min)

Notes: * Negative scoring.

Appendix 4. The full version of remote audit tool

Remote audit tool is based on the dense urban park audit tool framework adapted to allow it to be used for remote assessment of parks supporting physical activity in dense urban area contexts. To use this audit tool please follow these requirements:
a). Use Google Earth Pro for remote audits
b). Ask the auditor to fully review the audit tool before starting the audit.
c). Record the time the audit starts.
d). Ensure that all questions are completed and record the end time.

Basic information

Auditor:		Total audit time (min):	Audit date:	Park name:
Dimensions	**Criteria**	**Items**	**Response scale**	**Note**
Park surrounding and accessibility	Entrance points and signage	1. How many entrance points are there to access the park smoothly?	0. 1-2 1. 3-5 2. ＞6	0: The park has 1-2 entrance points open for people to enter. 1: The park has 3-5 entrance points open for people to enter. 2: The park has more than 6 entrance points or no boundaries completely open to access.
		2. Are there any signs showing the location or directions to the park?	0. No 1. Yes	0: No signs around the park showing the location or direction of the park. 1: There are signs around the park showing the location or direction of the park.
		3. Are there any park information at the entrance points?	0. No 1. Yes	Please consider the park information, such as, park name, map, opening hours, rules and prohibitions. 0: No park information at the entrance points. 1: There is park information at the entrance points.

	Traffic safety	5. Are there any crosswalks on the road to access the park?	0. No 1. Yes	0: No crosswalks on the road to access the park. 1: There are crosswalks on the road going to the park
		6. Are there any traffic lights on the crosswalk?	0. No 1. Yes	0: No traffic lights on the crosswalk. 1: There are traffic lights on the crosswalk.
		7. Are there any signs of speed limit on the roads to access the park?	0. No 1. Yes	0: No signs of speed limit on the roads to access the park. 1: There are signs of speed limit on the roads to access the park.
	Roads bordering the park	9. Are there sidewalks/bike lanes on the roads bordering the park?	0. No 1. Yes	0: No sidewalks/bike lanes on the roads bordering the park. 1: There are sidewalks/bike lanes on the roads bordering the park.
	Public transport station	12. Are there any public transport stations close to the park?	0. No 1. Yes	0: No public transport stations close to the park. 1: There are public transport stations close to the park.
	Parking lot	14. Are there any parking lots? (Specifically provided by the park.)	0. No 1. Yes	Please only audit the parking lot provided by the park. 0: No parking lots provided by the park. 1: There are parking lots provided by the park.
		15. Are there any bicycle racks? (Specifically provided by the park.)	0. No 1. Yes	Please only audit the bicycle racks provided by the park. 0: No bicycle racks provided by the park. 1: There are bicycle racks provided by the park.
		16. Is the parking free?	0. No 1. Yes	0: Parking is not free. 1: Parking is free.
Activity area	Sport court	18. What sports courts	18a. Basketball court 18b. Soccer court	0. No 1. Yes 0. No 1. Yes	0: No basketball court in the park. 1: There is basketball court in the park. 0: No soccer court in the park. 1: There is soccer court in the park.

are in the park?	18c. Baseball court	0. No 1. Yes	0: No baseball court in the park. 1: There is baseball court in the park.
	18d. Volleyball court	0. No 1. Yes	0: No volleyball court in the park. 1: There is volleyball court in the park.
	18e. Badminton court	0. No 1. Yes	0: No badminton court in the park. 1: There is badminton court in the park.
	18f. Handball court	0. No 1. Yes	0: No handball court in the park. 1: There is handball court in the park.
	18g. Tennis court	0. No 1. Yes	0: No tennis court in the park. 1: There is tennis court in the park.
	18h. Table tennis court	0. No 1. Yes	0: No table tennis court in the park. 1: There is table tennis court in the park.
	18i. Softball court	0. No 1. Yes	0: No softball court in the park. 1: There is softball court in the park.
	18j. Other, _____	0. No 1. Yes	0: No other court in the park. 1: There are other court in the park.
21. Are there any guidance or warning signs for sports court users?		0. No 1. Yes	0: No guidance or warning signs for sports court users. 1: There are guidance or warning signs for sports court users.
22. Are there any benches to rest on?		0. No 1. Yes	Please only consider benches within the sports court areas. 0: No benches are available within the sports court areas. 1: There are benches for rest within the sports court areas.
23. Are there any shade areas or shelter in the sport court?		0. No 1. Yes	Please only consider shade areas or shelter within the sports court areas. 0: No shade areas or shelter in the sports court areas 1: There are shade areas or shelters in the sports court areas.

	24. Are the sports court fenced?	0. No 1. Yes	Please consider if the sports court is fenced for protection. 0: No fencing of the sports courts. 1: There is fencing of the sports courts.
Playground	26. Are there any playgrounds in the park?	0. No 1. Yes	Areas offering equipment such as swings, seesaws, slides, trampolines, merry-go-rounds, rock-climbing are primarily for children and teenagers. 0: No playgrounds in the park. 1: There are playgrounds in the park.
	29. Are there any guidance or warning signs for playground users?	0. No 1. Yes	0: No guidance or warning signs for playground users. 1: There are guidance or warning signs for playground users.
Running track	31. Are there any tracks specifically for running?	0. No 1. Yes	Please only consider tracks that are specifically designed for running. 0: No tracks specifically for running in the park. 1: There are tracks specifically for running in the park.
Fitness area	34. Are there any fitness areas in the park?	0. No 1. Yes	Areas offering fitness equipment that is available for the public. 0: No fitness areas in the park. 1: There are fitness areas in the park.
	35. Are there any guidance or warning signs for fitness area users?	0. No 1. Yes	0: No guidance or warning signs for fitness area users. 1: There are guidance or warning signs for fitness area users.
Public /Green space	37. Are there any public /green spaces in the park?	0. No 1. Yes	Areas where people can freely access and conduct activities, such as kite flying, dog walking, chasing and playing, picnic. 0: No public /green spaces in the park. 1: There are public /green spaces in the park.

		39. Are there any guidance or warning signs for public /green spaces users?	0. No 1. Yes	0: No guidance or warning signs for public /green spaces users. 1: There are guidance or warning signs for public /green spaces users.
Facilities and Amenities	Path	41. Are there any walking paths in the park?	0. No 1. Yes	Please exclude the major roads in the park 0: No paths for walking in the park 1: There are walking paths in the park.
	Public toilet	46. Are there any public toilets in the park?	0. No 1. Yes	0: No public toilets in the park. 1: There are public toilets in the park
	Shelter and pavilion	49. Are there any shelters and pavilions in the park?	0. No 1. Yes	0: No shelters and pavilions in the park. 1: There are shelters and pavilions in the park.
		50. Are there any benches to rest under the shelters and pavilions?	0. No 1. Yes	Please consider only benches under shelters and pavilions. 0: No benches under shelters and pavilions. 1: There are benches under shelters and pavilions.
	Drinking fountain	52. Are there any drinking fountains in the park?	0. No 1. Yes	0: No drinking fountains in the park. 1: There are drinking fountains in the park.
	Bench	54. Are there any benches to rest in the park?	0. No 1. Yes	Please excluding all benches in themed areas such as sports courts, or playgrounds. 0: No benches to rest in the park. 1: There are benches to rest in the park.
		55. Are there any tree shades or coverage on the benches?	0. None 1. Some 2. A lot	0: There are few tree shades or coverage on the benches. 1: There are some tree shades or coverage on the benches. 2: There are sufficient tree shades or coverage on the benches.
	Picnic table	58. Are there any picnic tables in the park?	0. No 1. Yes	0: No picnic tables in the park. 1: There are picnic tables in the park.
		59. Are there any tree shades or coverage on the picnic table?	0. None 1. Some 2. A lot	0: There are few tree shades or coverage on the picnic table. 1: There are some tree shades or coverage on the picnic table. 2: There are sufficient tree shades or coverage on the picnic table.

	Trash can	61. Are there any trash cans in the park?	0. No 1. Yes	0: No trash cans in the park. 1: There are trash cans in the park.
Aesthetic	Vegetation and landscape	64. How many species of vegetation can you identify in the park? (Including flowers and plants)	0. <10 1. 11-30 2. >30	Please evaluate all plant and flower species by direct observation or signage 0: Less than 10 species of vegetation can be identified. 1: 11-30 species of vegetation can be identified. 2: More than 30 species of vegetation can be identified.
Safety	Lighting	69. Are there light posts in most areas of the park?	0. None 1. Some 2. A lot	0: No light posts in most areas of the park. 1: There are some light poles in most areas of the park. 2: There are a lot light poles in most areas of the park.
	Surveillance equipment	70. Is there surveillance equipment in the park?	0. No 1. Yes	Please assess by direct observation or signage. 0: No surveillance equipment in the park. 1: There are surveillance equipment in the park.
	Emergency device	71. Are there any emergency devices in the park?	0. No 1. Yes	Please consider emergency devices such as, fire alarms, fire hydrants, Automated External Defibrillators (AED), or health service stations. 0: No emergency devices in the park. 1: There are emergency devices in the park.
	Warning sign	73. Are there any warning signs in the park? (e.g., no swimming, no smoking, and dogs are prohibited).	0. No 1. Yes	Please consider warning signs such as no swimming, no smoking, and dogs are prohibited. 0: No warning signs in the park. 1: There are warning signs in the park.
		74. Are these warning signs clear?	0. None 1. Some 2. A lot	0: Warning signs are not clear and cannot be recognised clearly. 1: Warning signs are clear and can be recognised. 2: Warning signs are very clear and can be recognised quickly.