Title	A study on comprehensive walkability assessment in historical cities: the case of Xi’an and Kyoto
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Citation	大阪大学, 2023, 博士論文
Version Type	VoR
URL	https://doi.org/10.18910/92965
rights	
Note	

Doctoral dissertation

A study on comprehensive walkability assessment in historical cities: the case of Xi'an and Kyoto

（歴史都市における総合的なウォーカビリティ評価に関する研究：西安と京都を事例として）

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Abstract

The innovation on the means of mobility (transportation) and the change of the lifestyle of residents with 20 century modernization have brought about great changes in the spatial characteristics and the structure of street network in urban center of large cities. Especially in old historical cities that have been built as pedestrian-oriented, the spatial characteristics of street structure in small vernacular blocks has changed, and the amenity of the pedestrian space, which had been delicately maintained until now, have been lost. And with the increase in fossil-fueled mobility that has accompanied the modernization, its negative effects to global warming have become increasingly apparent. Climate change accompanied by Global warming is a serious issue that is rapidly altering the world we live in.

Currently, construction of low-carbon city has become an indispensable prerequisite for urban sustainable development. In today's means of transportation in the cities, strengthening walking can contribute to alleviating environmental pressures, relieving urban traffic congestion, maintaining the ecological environment, improving air quality and human health.

This study aimed to identify areas of improvement in historical cities that would encourage and facilitate walking activities as part of a larger effort to make pedestrian-friendly cities. Walkability is an important indicator when pursuing sustainable urban development, especially in the fragmented historical blocks affected by modern development. To this end, it examined the walking environments of two representative historical cities, Xi'an and Kyoto, as case studies, and comprehensively analyzed the specific effects of street structure factors and street scene factors to determine which aspects positively impact walkability.

Chapter 1 presented the general background of the study as well as the problem statement, objectives, and significance of the study. Included are explanations of the study areas and previous studies related to walkability.

Chapter 2 examined the changes in urban spatial structure and accessibility of street networks using the space syntax method during the process of modernization in the historical cities Xi'an and Kyoto as case studies. It was found that the values of Int-Rn, which indicate the degree of long-distance accessibility, for the two cities increased over the years. This suggests that the modernization of the two cities was heading toward motorization. Furthermore, the findings showed that the topological center in the main urban area of Kyoto expanded outward from 1902 to 2020 simultaneously in both the horizontal and vertical directions. On the other hand, in Xi'an, the area expanded from one topological center near a bell tower in 1949 to two topological centers in 2019. It was also found that intelligibility (meaning the connectivity of the respective regions) increased in both Xi'an and Kyoto. This suggests that the local centrality of the regional urban space was integrated with the global space.

Chapter 3 presented indicators developed for evaluating the walkability of a historic city obtained from reviewing previous research with the aim of identifying improvement areas that promote walking activity in a built environment in a historical city as part of pedestrian-friendly city planning. Using these indicators, we evaluated walkability in Xi'an and Kyoto, and examined the key factors that improve and hinder the walking environment in a historic central district. The findings showed that for assessing walkability in historical cities, combining macro-scale indicators that measure accessibility in terms of street structure at district scale and micro-scale

indicators of the built environment that affect daily human activities and walkability is very important. It was also found that these two types of indicators are independent of each other. In the case where both macro and micro indicators are relatively high, the places with good walkability in historic cities have relatively good accessibility, spacious sidewalks, and more vegetation in common. Furthermore, this research identified two types of walkable places: one with many attractive shops embedded in a traditional cultural street landscape, and another with an obstacle-free, clean and tidy built environment. The lessons of this chapter are that for Xi'an to improve walkability, the built environment and street infrastructure need to be improved by reducing obstacles and maintaining the historical street view. On the other hand, the findings showed that for Kyoto, while still maintaining its good walkable environment, the focus should be on improving the vitality of its streets.

For Chapter 4, we examined the changes in the street scenes of the main urban areas of Xi'an between before and after the COVID-19 pandemic through image segmentation by using street views of selected points. It was found that the basic street network or structure has remained essentially the same. However, while the proportions of “building,” “road,” and “vegetation” did not change substantially between the two periods, the proportion of the “presence of people” fell greatly, whereas the those of obstacles such as "fence/stall" and "motorcycles" increased. It revealed that such unexpected incidents as COVID-19 led the change of street scenes, thus these factors should be considered in walkability assessment for future research.

Chapter 5 summarized the major findings of this study, presented recommendations for future research, and concluded this thesis.

Acknowledgement

The present work is the result of all joint efforts. So many people had a part in the making of this dissertation that it is hard to acknowledge them all.

At the very first, I am honored to express my deepest gratitude to my dedicated supervisor, Professor Hirokazu Abe, with whose able guidance I could have worked out this thesis. He has offered me valuable ideas, suggestions and criticisms with his profound knowledge and rich research experience. His patience and kindness are greatly appreciated. Besides, he always puts high priority on our schedule for dissertation and is willing to discuss with me anytime available. I have learnt from him a lot not only about dissertation writing, but also the professional ethics. I am very much obliged to his efforts of helping me complete the dissertation.

I am also extremely grateful to Associate Professor Kensuke Yasufuku and Assistant Professor Akira Takahashi whose patient and meticulous guidance and invaluable suggestions are indispensable to the completion of this thesis, and extend my thanks to Associate Professor Noriko Otsuka for her tremendous kindness and support to me. Our seminar meetings were of significant importance to me from my teachers on enriching academia thinking and experience on doing research during my study.

Thanks are also due to my friends and classmates in Osaka University, who provide me with some technical assistance, as well as the friends who helped me do survey and evaluation for my research.

At last but not least, I would like to thank my family for their support all the way from the very beginning of my study. I am thankful to all my family members for their thoughtfulness and encouragement.

Time passes like this, day and night, spring and autumn, time flies. At this time, looking back on this four years' study road, I have experienced and gained a lot, and luckily met all the teachers and classmates on this journey. Thanks for meeting, I will take this beautiful memory to start the next journey, which will also become the motivation for me to do meaningful things in the future. Take care everyone, we see you around.

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List of Acronyms and Abbreviations

TD	Topological total depth
MD	Mean depth
Int-R3	Local integration
Int-Rn	Global integration
GIS	Geographic information system
DL	Deep learning
WES	Walkability Evaluation Scores
API	Application Programming Interface
PSG	Percentage of segments
SW	Streetscape Walkability
GSV	Google Street View

CHAPTER 1
Introduction

1.1 Introduction

The negative environmental effects of the fossil-fueled mobility associated with the modernization have become increasingly apparent. Among the more active transport modes, walking remains the cheapest way to travel and is accessible to almost everyone. Walking has a number of benefits, both personal and societal. It has widely been recognized that walking has a positive influence on improving the physical and mental health and well-being of urban residents (Frank,2006; Vanden, 2017). Walking also has the potential to relieve urban traffic congestion, enhance the ecological environment and air quality, and promote urban safety (D'Orso, 2020; Yencha, 2019). The system of streets and alleys forms a basic urban structure and plays an important role in maintaining the historical and cultural forms of the region in the modern built environment. In many instances, the social life of residents has been integrated into the historical and cultural districts of older cities, where the streets and alleys serve as a complex public space expected to accommodate a mix of social activities, leisure pastimes, and entertainment (Chen, 2016). As Jacobs (1961) stated, creating a good walking space is an important component of urban street planning, and one that has increasingly been recognized as an essential element in the redevelopment of historical cities in response to rapid modernization.

Inviting walkable environments stimulate commercial vitality on shopping streets, generating increased pedestrian flows (Tinessa, 2020) and play an essential role in reviving or preserving the historic and cultural values of traditional central areas in historical cities (Masoumzadeh, 2021; Jamei, 2021). Historical blocks tend to be pedestrian-friendly, and walking typically serves as the most important mode of transportation. In promoting the survival and redevelopment of historical blocks, the walking system can be considered the physical foundation for maintaining and protecting the spatial form and historic streetscape. Moreover, it provides important support for conserving the vitality of a city's historical and cultural blocks (Cui, 2015). Having been established well before the age of automobiles, the historical blocks in a number of cities have kept much of their walkable spatial scale and urban form (Bass, 2019). However, in adapting to automobile-oriented urban development, the walking environments in many have been significantly affected. Pedestrian networks have become fragmented, resulting in increasingly serious connectivity and accessibility problems for pedestrian traffic (Fan, 2022; Ren, 2020). Moreover, due to the lack of a well-maintained built environment (e.g., vacant buildings, old pedestrian infrastructure, and untidy streets), which makes walking unpleasant not only for the elderly and people with disabilities but also for the resident population in general as well as for tourists, pedestrian movement in historical districts has been restricted (Rosa, 2020).

Among the oldest cities in Asia, Xi'an, China, and Kyoto, Japan, have central urban areas developed around a grid, with a chess-board-like network of roads. Both are ancient cultural centers that include not only pedestrian-friendly historical urban blocks, but also automobile-oriented modern urban areas (Ihc-s, 2022). Unlike many historical cities in Europe, Xian and Kyoto have faced extensive challenges in preserving their historic urban structure due to urbanization and motorization, as their streetscapes have not been well preserved; thus, modern and historical blocks are combined within the central historical districts (Ma, 2014). In addition, their grid-based street networks have made it easier for cars to enter the historical centers (Campisi, 2020), and the co-existence of automobiles and pedestrians has become problematic. Few prior studies have compared two Asian historical cities that have similar urban structures as well as distinctive development characteristics associated with their modernization (Cerin, 2011; Hanibuchi, 2019; Zeng, 2020).

The main purpose of this study is to identify the inherited problem of historical cities regarding walkability using a comprehensive indicator of evaluative factors that tend to either improve or hinder the walking environment in the historical central districts of such cities. Given the similarities in their history and the urban form of their historical central areas, the cities of Xi'an and Kyoto were selected as appropriate case studies.

1.2 Objective and significant of the study

This paper takes Xi'an and Kyoto as examples to examine the walkability of historical capital cities. The ultimate aim is to identify improvement areas in the historic built environment that will promote and facilitate walking activities as part of an overall effort to create a pedestrian-friendly city. And the policy implications to improve in the built environment will be explored.

In order to realize the aim, this paper has set 4 objectives below:

A) To clarify the changes in urban spatial structure and accessibility of street network during the modernization process in the historical cities (Xi'an and Kyoto) by using space syntax.

B) To examine an index for evaluating the walkability of a historic city through reviewing the previous research

C) To evaluate the walkability with these indicators in Xi'an and Kyoto,

D) To identify changes in the street environment in Xi'an by the COVID19 pandemic.

Through the above research, historic cities' inherited problem for walkability will be identified through a comprehensive evaluation of factors improving and hindering the walking environment in historical central districts. Improving to walkable environments stimulates commercial vitality on shopping streets, generating increased pedestrian flows. This research plays an essential role in reviving or preserving the historic and cultural values of traditional central areas in historical cities. Moreover, it can contribute to alleviating environmental pressures, relieving urban traffic congestion, maintaining the ecological environment, improving air quality and human health.

1.3 Literature review

1.3.1 Urban spatial structure

Previous studies of the urban morphology of the cities include a study by Onishi (1993), who conducted a detailed investigation of the changes in the townscape of Xi'an's historic center and compared them to developments in Kyoto. Kang (2017) studied the spatial morphology characteristics of Xi'an's Historic District using traditional spatial morphology analysis, mostly in terms of spatial layout, texture, street scale and plane form. Compared to investigative analyses(above) that focus on traditional morphological characteristics, more recent spatial morphology analysis is mainly carried out using quantitative methods and is mainly focused on space syntax with a GIS data platform.

In an empirical and quantitative study of large-scale urban streets and roads in three separate periods, Huang (2010) investigated the complex evolution of the morphological characteristics of the typical urban Hui culture from the morphological center, street structures and network systems perspective, and examined the shift in the topological relationship between historic block space and urban whole space.

Kigawa (2005) conducted an analysis of Kyoto's spatial configurations throughout the ages and its urban planning project based on space syntax, revealing that streets had a strong impact on Kyoto's transformation from its early modern to modern form. However, there are few comparative studies between similar blocks.

Space syntax is important for extracting the topological structures of a city, particularly when comparing two or more cities. Kigawa (2009) also used space syntax to analyze the process by which the castle cities had been reformed. In studying the process of urban modernization in several of the castle cities of Japan, he found distinct differences among the cities. He also found that the global integration is related to motor vehicle traffic, while the local integration is mostly related to pedestrian traffic. In China, a comparative study of urban space based on space syntax was conducted by Wang et al. (2012), who selected cities with wide differences in road networks and land configurations on ArcView platform. Analyzing the axial line, the study explored differences and commonalities. Such studies help us to understand core area aggregation and urban morphology evolution inertia.

1.3.2 Measuring the walkability

For analyzing and measuring the walkability in built environment, various measures can be used to assess the walkability of an area. An area's ability to do errands on foot from a residential location is often reflected by a walkability index. Walkability index is an important indicator for evaluating sustainable urban mobility. Extensive prior research has developed various walkability assessment indicators that can be measured quantitatively. A large portion of the quantitative assessment of walkability is based on GIS data (city or neighborhood level). As evidenced in instances like the EPA's National Walkability Index, indicators of urban form, such as intersection density, street connectivity, proximity to transit stops, and diversity of land use, are frequently employed for walkability evaluation (EPA, 2021). Land use information is also used in the UK's walkability heat maps based on space syntax to count the variety of common urban facilities that are within a five-minute walk (Stonor, 2021).

The measurement of street-level walkability has become increasingly valued; however, taking the necessary measurements requires extensive observation, which, in turn, takes considerable time and is highly labor-intensive (Ewing and Handy, 2019; Otsuka et al., 2021; Zhu et al., 2017). Virtual audits using street view images represent a new thought in assessing the micro-scale environment, it offers an alternative to field observation based on remote audits, as they are more cost-efficient due to the elimination of travel time and provide greater safety for roadside auditors.

In recent years, various studies have effectively evaluated micro-scale walkability utilizing Google Street View (GSV), which is a means to minimize expenses, conduct remote evaluation, and automatic assessment of communities in a global context (Nagata, 2020; Rzotkiewicz et al., 2018). Pliakas et al. (2017) showed that, when compared to traditional on-site audits, GSV-based audits not only save time but also retain audit quality. Moreover, Hanibuchi et al. (2019) designed a simple checklist for virtual assessment of street view walkability (SW) and shown the reliability of GSV evaluation across sources (face-to-face and virtual audits) and raters (between two trained auditors and between trained auditors and untrained crowd sourcing workers).

In the automation method, several studies examine the photos from GSV and comparable services (like Tencent Street View) and extract the street view features using machine learning or deep learning techniques. This research examined the associations between each component and walkability, physical activity, or walking behavior in streetscapes (Lu, 2018; Villeneuve et al., 2018; Yin and Wang, 2016). For instance, Yin (2015 and 2019) employed a deep learning algorithm to identify certain details in street sceneries and produce precise measurements.

Above all, the evaluation of walkability not only involves traditional perceived evaluation but also pays more and more attention to quantitative evaluation, especially combining automated image segmentation of deep learning. However, these two aspects are rarely applied in historical blocks.

1.3.3 Impact of COVID19 on walkability and pedestrian streetscape environment

Since its emergence in 2020, the COVID-19 pandemic has had a huge impact on the health and well-being of people worldwide; regrettably, many countries have experienced a two-wave (or even a three-wave) pattern in reported cases. Globally, there have been more than 760 million COVID-19 cases, with the total number of deaths exceeding 6.9 million (WHO,2023). Furthermore, it seems clear that the pandemic will have a long-term impact on our individual behaviors, lifestyles, mobility, and travel patterns such as commuting (Shamshiripour,2020; Shaer,2021;

Harrington,2022), all of which will profoundly affect urban transport systems (ITDP, 2022; Wang, 2022).

While stringent containment measures have stopped the virus from spreading throughout China, people's movement and activities have been severely constrained, which has significantly decreased walking. Walking has also been acknowledged as being advantageous for the prevention of disease and having a favorable impact on human health (Frank, 2006; Vanden 2017). Oishi (2021) discovered that walkable communities had fewer COVID-19 cases, allegedly because it allows individuals to complete their daily tasks close to their houses. It is noteworthy that neighborhood walkability seems to even provide a type of protection against the spread of COVID-19.

1.4 Context of Xian and Kyoto

1.4.1 Xian, China

Xi'an, located in the northwest of China and the middle of Guanzhong Plain, is adjacent to Qinling Mountains in the south, Weihe River and Loess Plateau in the north, and is the capital of Shaanxi Province. By the end of 2021, the permanent population of the city was 13.16 million. Xi'an, as a leading city in the western region, a national central city and a world famous historical and cultural city, it covers an area of 10752 square kilometers, of which the urban area is 701 square kilometers. The main urban area of Xi'an is within the city wall, and the bell tower in its center forms four vertical trunk roads to the southeast and northwest, forming the main urban structure of the main urban area.

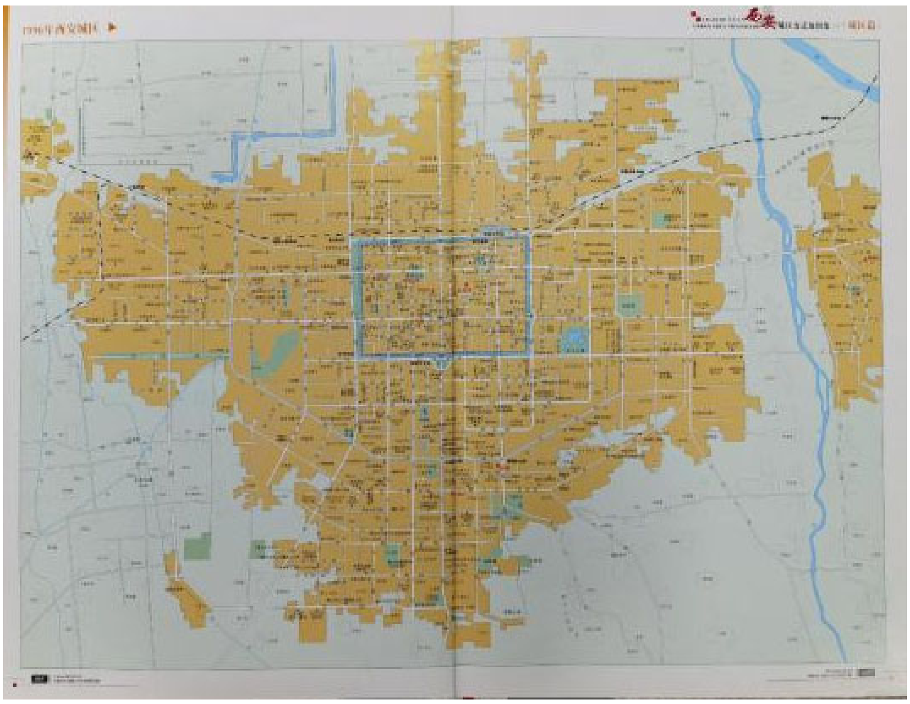

Fig. 1-1 Maps of Xi’an (1996)

Xi'an is the oldest ancient capital from 1097 BC to 904 AD. In the late Tang

Dynasty, only the imperial city of Chang'an was preserved and rebuilt as a new city, which is a residue of traditional Guanzhong residents. After several dynasties to the Ming Dynasty, this new city was named Xi'an for the first time, and the city was greatly rebuilt. As a result of the construction of this period, the form skeleton of the central part of Xi'an city (inside the city wall) was determined, and it has continued to this day, that is, with the bell tower as the center, the four streets intersect directly here, and the end view of the four streets is matched with the city tower. In the Qing Dynasty, there appeared a special land arrangement in the northeastern part of the city, which was completely built a Mancheng District and was used as military land.

In 1911, the 1911 Revolution broke out, The Kuomintang government has redeveloped the Mancheng District and built the main roads of East Five Road, West Five Road, Jiefang Road and Heping Road, which make the northeastern streets grid-shaped and the roads wider, forming a new urban area.

After the founding of the People's Republic of China in 1949, China began its modernization construction from 1949, its urban areas have expanded dramatically to the East, South and West from the old city.

1.4.2 Kyoto, Japan

Kyoto is the capital city of Kyoto Prefecture, Japan. It is located in the Kansai region on Honshu Island. Kyoto is an inland city, which together with Osaka and Kobe forms part of the Keihanshin metropolitan area. By 2020, the city has a population of 1.41 million and a total area of 827.90 km^2. Kyoto radiates to the southeast and northwest on the basis of Heiankyo, with grid roads as its main street structure.

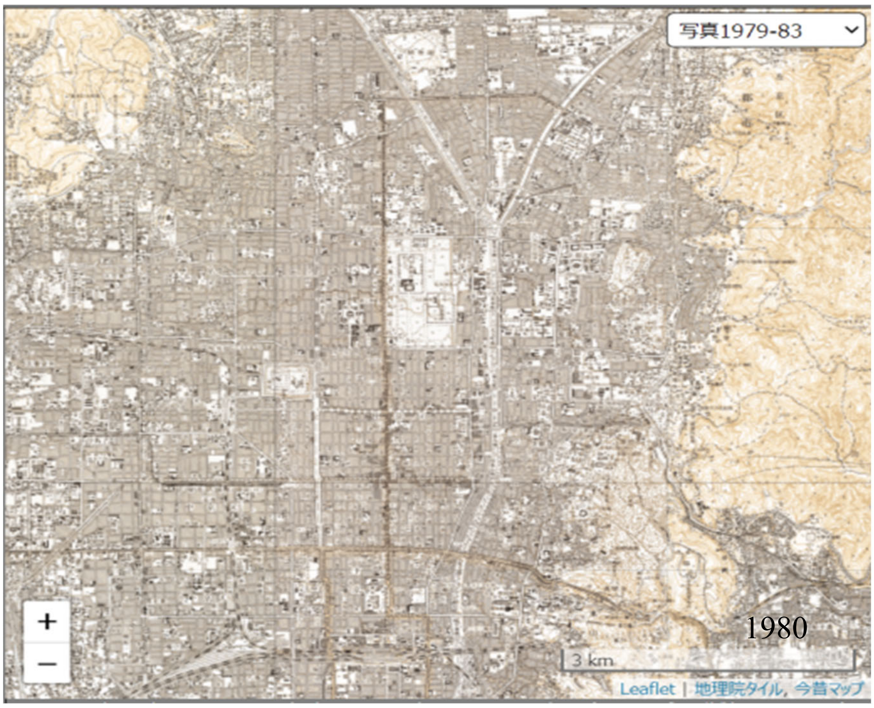

Fig. 1-2 Maps of Kyoto

From 794 to 1868, Kyoto was the capital of Japan. At the beginning of 794 AD, it was built in the shape of an orthogonal grid. Until premodern times, Kyoto was burned many times; The original shape of Kyoto has disappeared. Today's towns were built in the premodern era. At that time, Kyoto divided the orthogonal square into two rectangles, moved the temple to the edge of the town. Today's central urban area of Kyoto city was developed in the Edo era (1603-1867).

After the Meiji Restoration, at the end of the Edo era, the political system underwent tremendous changes. In 1868, the capital moved to Tokyo. As the civil war destroyed Kyoto, during the Meiji period (1868-1912), the new Japanese government tried to restore Kyoto and took some urban planning measures. This includes widening several traditional streets and establishing a tram system on these streets (Kigawa, 2009).

At the end of the Meiji period, Kyoto also entered the next stage of modernization. By the Taisho period (1912-1926), Kyoto had recovered its economic status, and cities had accepted the inevitability of migration from rural areas. Due to the rapid expansion of the population, the farmland around the conventional urban areas has also rapidly become urban areas. In order to solve the problem of disorderly and chaotic development, a 1922 urban improvement plan came into being. As there are many important traditional temples in the center of Kyoto, the plan proposes to build a ring road around the traditional Kyoto area for residential development (City of Kyoto,1944). After the high growth policy period in the 1960s, the speed of opening-up was accelerated. Large scale suburban areas were opened up and roads were widened.

1.4.3 Historical blocks

The historical blocks in Xi'an and Kyoto are mainly pedestrian, walking is the most important mode of transportation historical blocks. However, as the main walking space in historical areas, there are also many practical problems especially in Xi'an. as the main walking space in historical blocks, there are also many practical problems, especially in Xi'an such as insufficient supporting facilities, serious dilapidated and damaged facilities, poor environmental health conditions, obvious conflicts between people and vehicles, and gradual loss of landscape features. These problems constantly threaten and inhibit the survival and development of historical blocks (Dong, 2019).

In particular, while the historical blocks attract a large number of tourists, the deterioration of the pedestrian space environment has laid a serious hidden danger for the continuation of the vitality of the Xi'an historical block. It’s urgent for Xi'an historical blocks to improve and optimize the walking environment, and improve the quality of the space environment of the streets and lanes. Xi'an began exploring the development of cultural and commercial pavement for tourists in historical blocks in 2005(Wang, 2019). Later, Xi’an government promote slow walking as the main traffic mode in the historical old city, and also has starting to comprehensively update and transform the pedestrian environment in the historic district since 2017(Xi'an planning bureau, 2020).

Also, for Kyoto, it has a long history of more than 1200 years, while guarding interesting streets, natural landscapes, traditions, cultures, etc. Moreover, Kyoto has created a city where everyone can walk comfortably, mixed-use and walkable streets are inherent features of old cities in Japan. However, in the era of rapid modern development of car centered life, such urban charm has been damaged, and many developments have occurred along wider streets, and Kyoto's walkable areas are now fragmented (Yoshii, 2015). The Kyoto city government also proposed that the main mobile mode suitable for Kyoto should pay more attention to walking. People coming and going are an important source of city liveliness and vitality, and walking is the ideal of health and environment. In order to promote "Walking City" for Kyoto, walkable city planning, and charter have been discussing since 2009(City office, 2022). Based on these, the walkability evaluation research of historical blocks in two cities both are very important.

1.5 Structure of the dissertation

This dissertation consists of 5 chapters as follows:

Chapter 1.

In Chapter 1, demonstrates research background of the study, significance and the objectives that establish the main aim of this research. In addition, it elaborates the organizational structure of the research frameworks and methods.

Chapter 2.

In this Chapter, we analyze of urban spatial structure changes during the process of modernization in historical cities, focusing on historical capital cities, Xi'an and Kyoto.

And then we investigate the evolution of the morphological characteristics of the typical walking space from the street structures and network systems perspective, and will examine the shift in the topological relationship between historic block space and urban whole space.

Chapter 3.

This chapter firstly identify suitable indicators for evaluating the walkability of historic cities after reviewing previous research with the aim of promotion walking activity in a historic building environment.

Following that, we evaluate the walkability in Xi'an and Kyoto by the checklist using these indicators and identified the key factors that improve and hinder the walking environment in the historic central district using the results from the two case studies.

Chapter 4.

This chapter comparing the specific street view element before and after the pandemic based on image segmentation of deep learning as a case study in Xi'an to identify the change of pedestrian street landscape environment due to the Covid-19. It fills the research gap of the impact of the pandemic on the walkability.

Chapter 5.

Last Chapter presented a summary of the research findings and conclusions obtained from the whole study, and the limitations of the study and recommendations for future research.

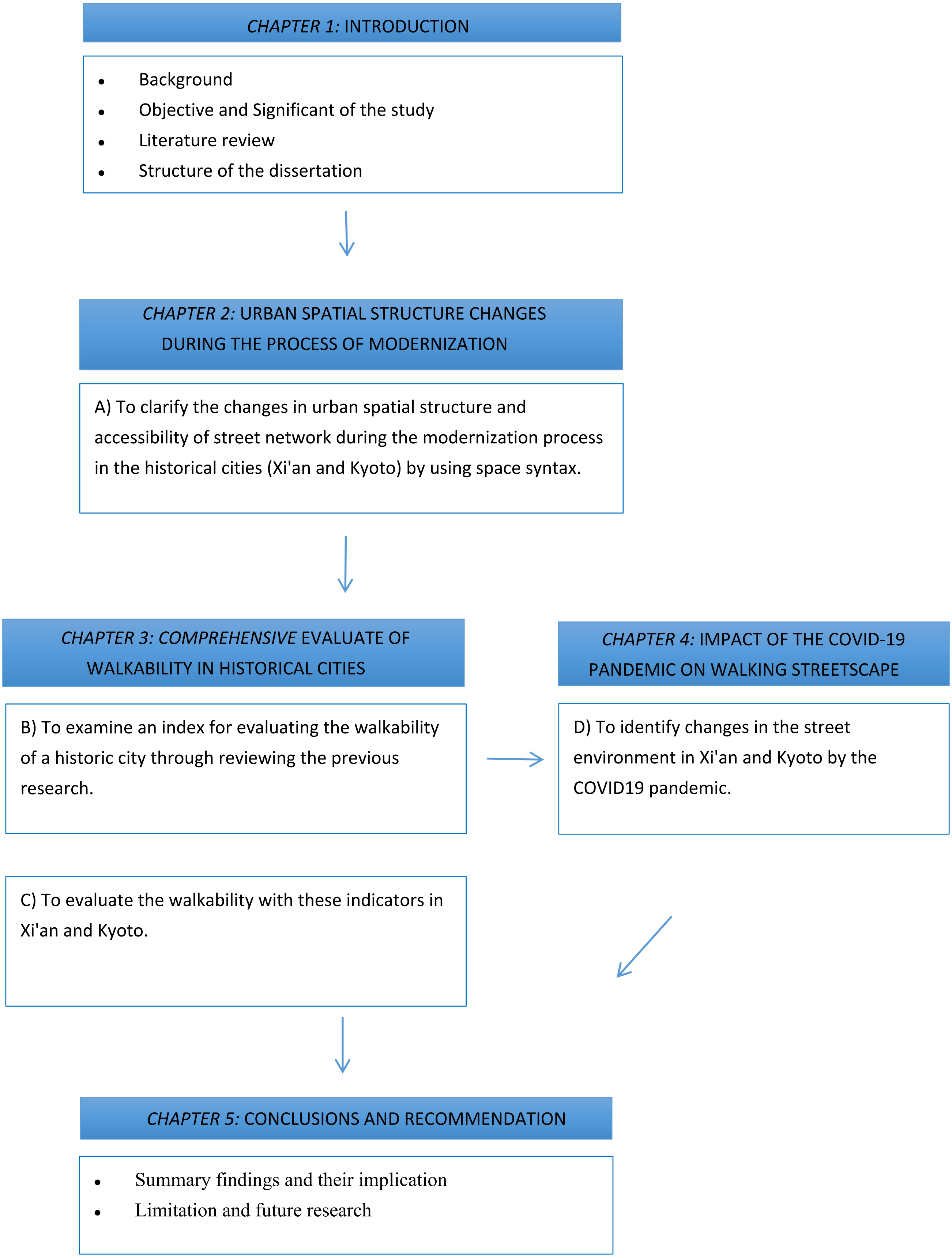

Fig. 1-3: The structural organization of the thesis

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CHAPTER 2

Urban spatial structure changes of street network during the process of modernization in historical cities

2.1 Introduction

Chapter 2 examined the changes in urban spatial structure and accessibility of street network during the process of modernization in historical cities which is Xian and Kyoto as case studies.

Both Xi'an, China, and Kyoto, Japan, are historic cultural centers whose major metropolitan centres have grown up on a grid of roadways like a checkerboard. In terms of morphology, the two are comparable, but they have also had their own specific development features throughout their modernization.

The Ming City District is the core area of Xi'an, which was built on the basis of the imperial city of the Sui and Tang Dynasties during the Hongwu Period of the Ming Dynasty, and which has retained many of its original areas (Xi'an Municipal Bureau, 2020). The Ming City District is the center of Xi'an's urban human settlements, especially in its southwest area's remaining historic and cultural block of Beiyuan Gate and Sanxue Street, which inherited the best historical characteristics of the region and streets. With the founding of the People's Republic of China (1949), China began its modernization construction. Since that time, Xi'an has experienced four master plans, and its urban areas have expanded dramatically to the East, South and West from the old city, growing from 13.2 to 701 square kilometers (Ohnishi, 1993); during this period, the population has also increased, from 2.27 to 13.2 million.

With the rapid expansion and development of the city area, the form and structure of the main urban area within the city wall has changed significantly, and a large number of historical alleys have been rebuilt while others have disappeared in the historic blocks of the main city.

Japan began its modernization construction in the Meiji period (1868-1912), during which time the new Japanese government began to restore Kyoto (Kigawa, 2005). A number of urban planning measures were carried out, widening streets and creating a ring road, all of which had the effect of accelerating the city's modernization. In the Showa period (1926-1989), the city merged with surrounding towns, rapidly and significantly expanding its urban area from 31 to 210 square kilometers. The population increased from 0.28 million in the Meiji period to 1.41 million (Ohnishi,1992; Japan Geographic Data Center, 2020). The city's urban development is still mainly characterized by grid planning, and the main urban area is dominated by Kamigyo

Ward, Nakagyo Ward and Shimogyo Ward. As in Xi'an, the modernization construction in Kyoto has greatly changed the urban area and street morphology of the city through urban planning.

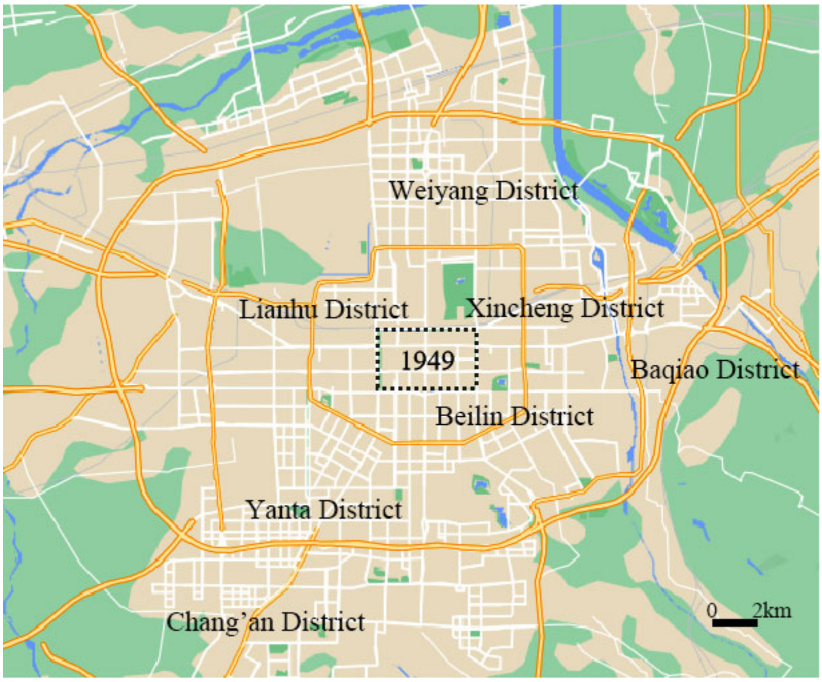


Fig. 2-1 Map of Xi'an (From 1949 to 2019(Google Map))

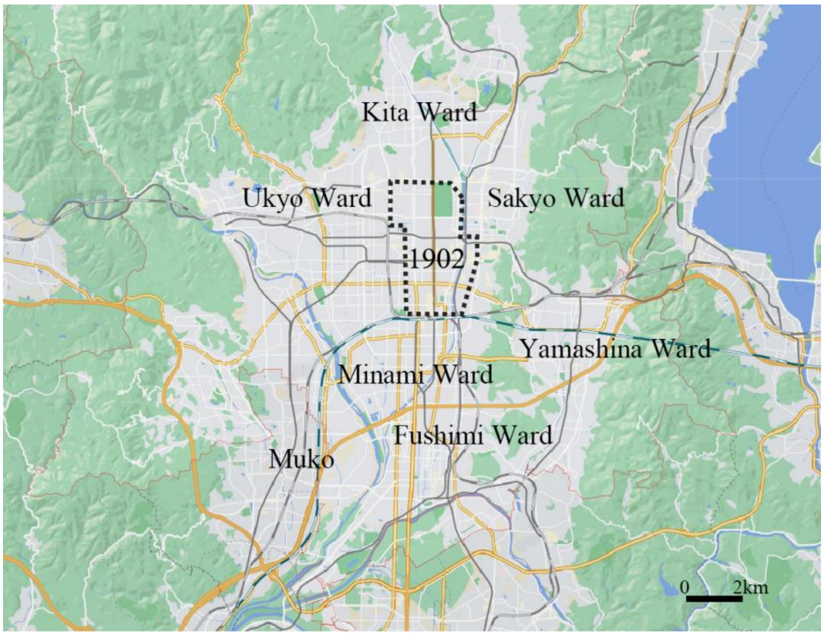


Fig. 2-2 Map of Kyoto (From 1902 to 2020(Google Map))

This chapter compares the urban spatial structure changes in Xi'an and Kyoto in their respective modern city construction. In the process, we not only make a comparison of similar cities in different development stages, but also provide a vertical analysis of the relationship between their global and local accessibility aspects. Using a comprehensive quantitative analysis of the current urban development situation and its distinctive characteristics, we compare axis maps of the main urban areas of Xi'an and Kyoto in different years, and analyze the changes in their topological centers as well as the global and local integration relationship in their main urban areas.

2.2 Method (Space syntax and space analysis)

Space syntax is a set of theories and analytical tools introduced in “The Social Logic of Space” by Hillier and Hanson in 1984 (Hillier, 1984). Topological analysis focuses on the connection between spaces. We examined the street network of the historical capital districts in two steps:

First, we use an axial analysis to investigate the street network, then compare the axis maps of Xi'an and Kyoto in different years, tracing the changes in their topological centers. (The axial map is constructed by taking an accurate map and drawing a set of intersecting lines through all the spaces of the urban grid so that the grid is covered, and all rings of circulation are completed.)

Because the urban morphologies of the two cities have undergone dramatic changes in modern times, we chose the beginning period of the modernization construction of the two cities as the contrastive object. The starting point examined in this study for Xi’an is the founding of the new China in 1949; the starting point for Kyoto is the year of the earliest measured map (1902) in the Meiji period of the new Japanese government. The study area for Xi’an focuses on the main urban areas that served as the Ming castle city (13.2 km2). The main study area for Kyoto (21.2 km2) consists of three districts (Kamigyo Ward, Nakagyo Ward and Shimogyo Ward). With respect to Xi’an, the key objects used in the study include four maps of narrow streets in the old city 1949 road network, together with a remote sensing image of Xi'an in 2019. In the case of Kyoto, the key objects are a field survey map from 1902 and a cadastral map from 2020.

In order to analyze the configuration layout of each city, we translated the actual spatial structure into an axial map (Fig. 2-3), which is the least set of longest lines drawn tangent to vertices that can see each other. For our topological analysis, the axial map was projected onto a justified graph in which the axial lines are represented as nodes, and the intersecting lines are the connections between the nodes (Hillier, 1984). Fig. 2-3 shows a justified graph that has been converted from an axial map (Woochul, 2012). A justified graph is one in which a node is drawn at the base, and all the points of various depths are drawn above it. Specifically, all the points at depth 1 from the starting point are aligned horizontally immediately above it, all the points at depth 2 from that point are drawn above those at depth 1, and so on, until all levels of depth from the initial point are accounted for. The topological total depth and mean depth can then be determined from the justified graph.

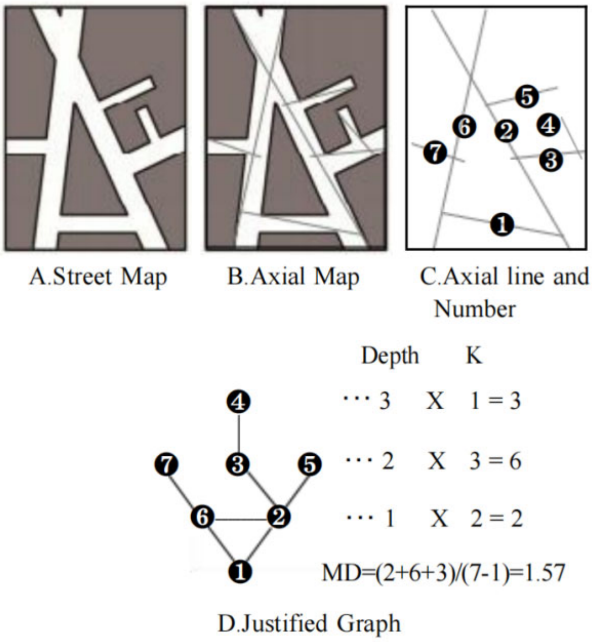


Fig. 2-3 Axial analysis

Total Depth (TD)

↓

Mean Depth(MD) $= \dfrac{TD}{n-1}$

(Eliminate the effect of numbers)

↓

Relativized Asymmetry(RA) $= \dfrac{MD-1}{\frac{n}{2}-1}$

(Eliminate topological symmetry)

↓

Relativized Relativized Asymmetry (RRA) $= \dfrac{RA}{RAoD}$

(Eliminate topological symmetry and describe difference from the standard deviation)

↓ ↓

RA of Diamond (RAoD) (Standard value)

↓

$$\frac{n\left\{\log_2\left(\frac{n}{3}\right)-1\right\}+1}{\frac{(n-1)(n-2)}{2}}$$

Integration$= \dfrac{1}{RRA}$

↓

$$\frac{n\log_2\left(\frac{n}{3}\right)-n+1}{4TD-4n+4}$$

Fig. 2-4 Flow chart from depth to integration

n: total number of vertices

A depth value represents the convenience of moving from one space to another. The topological distance between two adjacent nodes is one step. The shortest topological distance between any two nodes—that is, the number of spatial transformations—is expressed as the depth value between the two nodes. The larger the value, the deeper the element is hidden in the network of the study area.

Topological total depth (TD) is the cumulative total of the fewest topological depth paths between all pairs of nodes. MD (mean depth) is the average of the minimum number of steps from one node to all the other nodes in the system, which eliminates the effect of numbers.

Next, integration is introduced as an important result of the axis analysis. Its value is derived from the value of the topological depth, as in Fig. 2-4. By analyzing the integration value, it is possible to determine the degree of a street and how topologically shallow or deep the entire system is from a point on the street. An integration value essentially describes the "accessibility" of an element in the study area network. The higher the depth value, the lower is the degree of integration, that is, the worse is the connectivity, and vice versa. More specifically, axial local integration is defined as the integration values of the axial lines at radius 3 (root plus two topological steps from the root) which can be used to represent a localized picture of integration. Axial global integration is defined as the integration values of axial lines at an infinite radius which can be used to represent the integration pattern at the largest scale.

Finally, the integration core can be used to represent the change and transfer of the topological center, consisting of the most integrating 10% of the axial lines (Hillier, 1984; Hillier, 1993).

In the second step, the results of the topological analysis conducted in the previous step are used to analyze the global and local accessibility relations of the respective main urban areas. Intelligibility indexes the degree to which the number of immediate connections that an axial line has is a reliable guide to the importance of that axial line in the system as a whole. (Specifically, it is the correlation between local and global elements). Thus, intelligibility is introduced as a way to describe the correlation between local integration and global integration and as the means to measure whether the local space and the global space environment are related and unified. This relationship indicates whether an area is intelligible in its global context (Hillier, 1987; Tuncer, 2007).

Intelligibility: $$R^2=\frac{[\sum(Int\_R_3-\overline{Int\_R_3})(Int\_R_n-\overline{Int\_R_n})]^2}{\left[\sum(Int\_R_3-\overline{Int\_R_3})^2\sum(Int\_R_n-\overline{Int\_R_n})^2\right]}$$ Eq. (1),

The value of intelligibility (R^2) is calculated by Equation 1, where Int-Rn is the global integration (all-step) of any axial line in space, and Int-R3 is the local integration value (three-step) of any axial line in space. $\overline{\text{Int-R3}}$ and $\overline{\text{Int-Rn}}$ are the mean values of global integration and three-step local integration, respectively.

For Eq. (1), if the intelligibility of the local space is high, the indication is that the centrality of local space can be integrated into the global spatial structure. The natural movement of local space can not only bring movement economy; it can also produce a greater multiplier effect in the process of functional interaction with the movement economy of global space. On the other hand, if the intelligibility of local space is low, the indication is that the local centrality of the regional urban space cannot be integrated with the global space and is thus relatively isolated (Hillier, 1993; Hillier, 1996).

2.3 Results and discussion

2.3.1 Changes in the main urban areas of Xi'an and Kyoto

2.3.1.1 Main urban area of Xi'an

Fig. 2-5 Axial maps with Int-Rn (Global) for Xi’an in 1949 and 2019

The two axial maps of Xi'an (1949 and 2019) shown in Fig. 2-5, allow us to examine the change in the urban topological center. With the development of lattice sub-trunk road planning, many narrow alleys were expanded and new roads throughout the castle district were constructed. The global integration value (Int-Rn) of Lianhu Road, East 5th Road and West 5th Road to the north of the central axis, Jiefang Road and Heping Road to the east of the Central Axis is high. This suggests that the topological center of the street network has extended to the north side roads of the main road centered on the bell tower.

The remaining historical and cultural blocks of Beiyuan Gate and Sanxue Street in the western and southern areas of Ming city, with low Int-Rn, were far from the topological center of the main crossroad centered on the bell tower and the northeastern part of the castle city in 1949. The average Int-Rn of the two historical blocks is 1.56 and 1.58, respectively, which is lower than the average global value of 1.71 in 1949. By 2019, the average Int-Rn had increased from 1.71 to 1.91, over which time the values for the two historical blocks increased to 1.88 and 1.74, respectively, both of which are lower than the 1.91 global average. However, the percentage change for the Beiyuan Gate block (18%) is greater than the global average (12%), while the percentage change for the Sanxue Street Block (10%) is slightly lower. The indication is that the historical blocks in the main city area experienced a high degree of local change with urban global space development. The local development of the historic blocks is clear.

2.3.1.2 Main urban area of Kyoto

Fig. 2-6 shows the 1902 and 2020 axial maps with Int-Rn for Kyoto. The streets with high integration values based on the results of the axial analysis are more darkly shaded.

In 1902, the highest integration values are for Karasuma Street, Horikawa Street and San-Jyo Street, which constitute the urban topological center, as seen in the two maps. The highest vertical axial Int-Rn extended outward and westward to Nishiohji street in 2020. The highest horizontal axial Int-Rn expanded from San-Jyo Street to Shi-Jyo Street. High connectivity is also seen for Go-Jyo Street and Shichi-Jyo Street. The topological center extended outward in both the horizontal and vertical directions simultaneously. The average Int-Rn of the three Kyoto wards increased from 1.4, 1.62 and 1.54, respectively, in 1902 to 2.18, 2.46 and 2.37 in 2020, corresponding to respective change rates of 55.7%, 51.8% and 53.9%. The fact that the change rates are not substantially different from the global change rate (53.6%) indicates a strong consistency in global street construction. The average Int-Rn of the Gion historical blocks is increased from 1.27 to 1.99 with change rates of 55.7%, which is also not significantly different from the average value.

As can be seen here, the topological centers of both cities changed correspondingly with the outward expansion of the urban area. In the main urban area of Kyoto, the consistency of street construction is stronger and the change in global accessibility is more obvious. In Xi'an, the global change in the main city is not nearly as clear. While Xi'an's main urban area has been strongly affected by the urban expansion outside of the castle city, the residential areas inside the city wall also have obvious characteristics of local development. The external driving force of urban global space development and the internal traction of block evolution appear to have interacted with each other to jointly promote the development of the structure of the historic blocks.

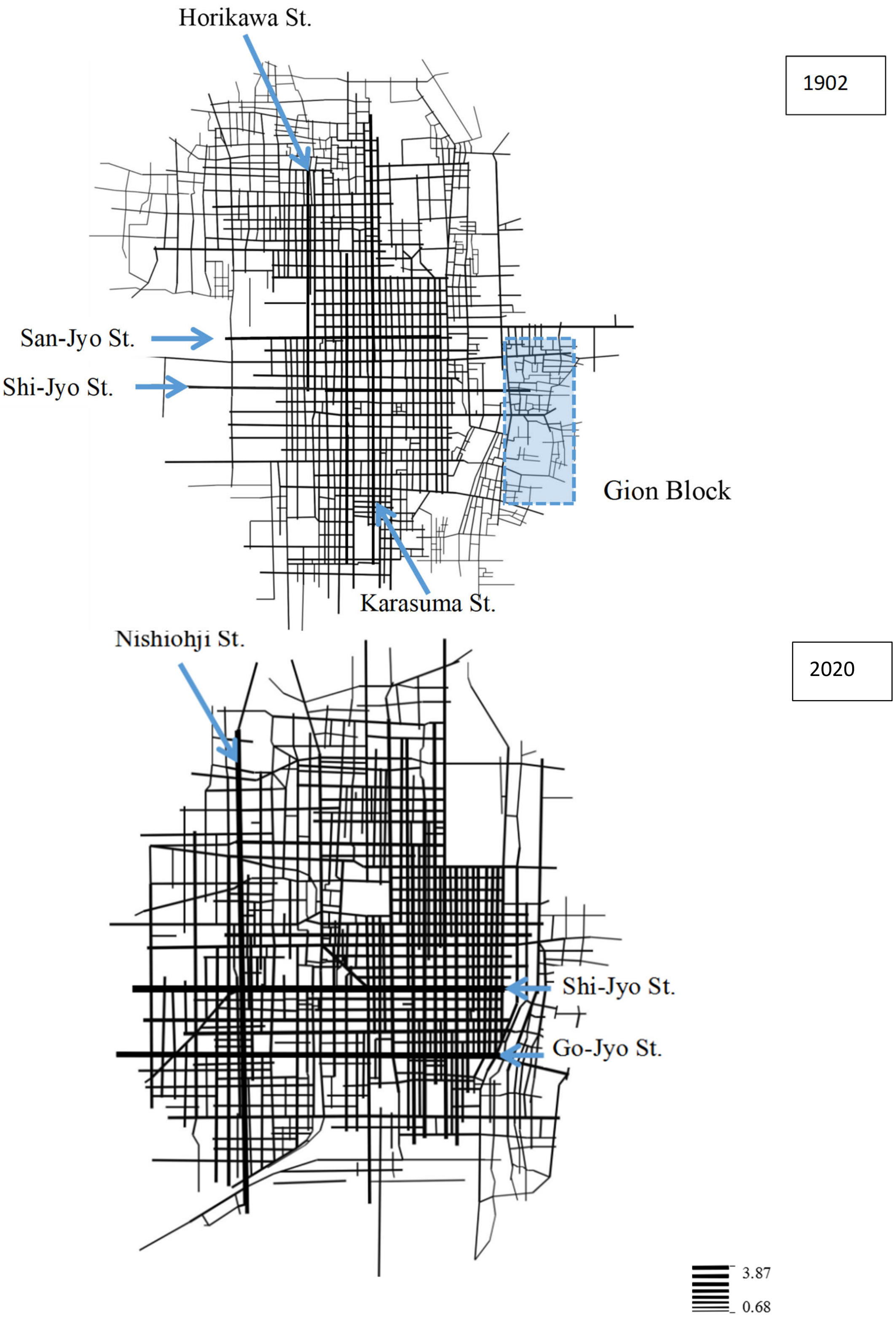
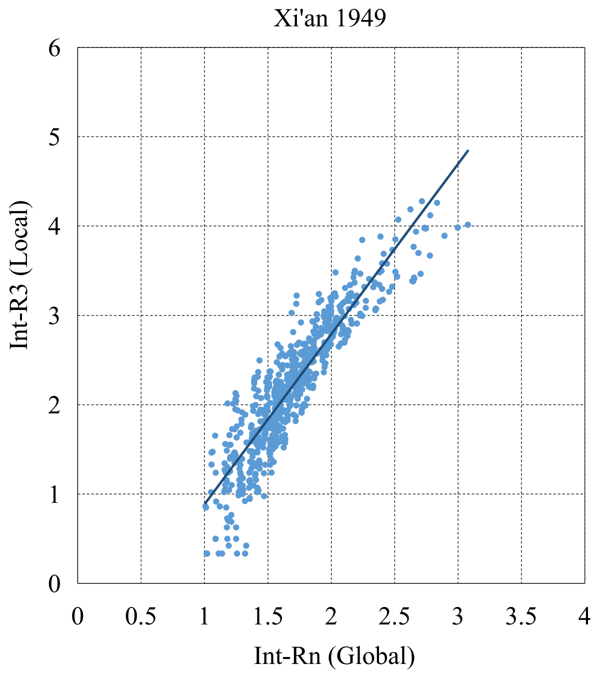


Fig. 2-6 Int-Rn (Global) for Kyoto in 1902 and 2020

2.3.2 Scatter diagram analysis

Scatter diagrams for Xi'an showing Int-Rn on the horizontal axis and Int-R3 on the vertical axis are provided in Fig. 2-7. It is apparent that the distribution shapes of the scatter points in 1949 and 2019 show little similarity. In 1949, Int-Rn was relatively low, and the scatter points are concentrated in the lower left portion of the diagram.



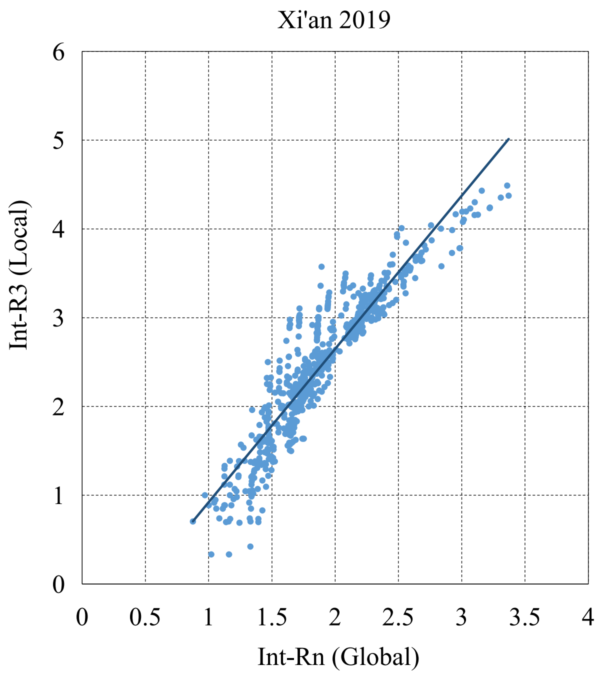
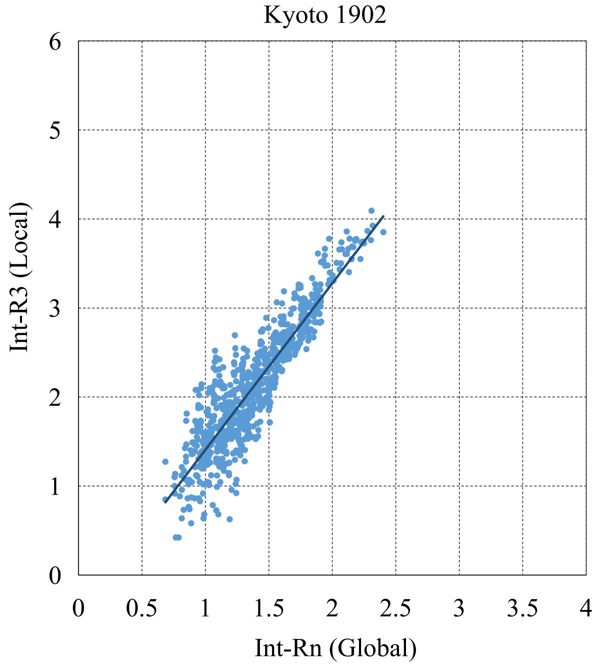


Fig. 2-7 Int-Rn/R3 (global and local) scatter diagrams for Xi'an in 1949 and 2019

In 2019, the concentration of the scatter points has shifted toward the middle, and the average Int-Rn has increased, indicating that the Int-Rn of Xi'an's axial line became stronger in the process of the city’s modern urban spatial development.



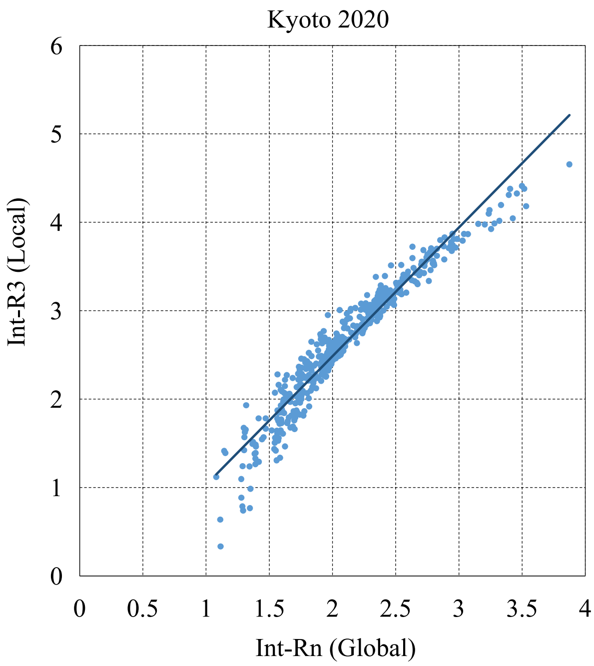


Fig. 2-8 Int-Rn/R3 (global and local) scatter diagrams for Kyoto in 1902 and 2020

Fig. 2-8 gives the Int-Rn/R3 (global and local) scatter diagrams for Kyoto. As shown, the center of the dense area of the scatter points moves rightward over the period of 1902 to 2020. The average value of Int-Rn increased markedly as the Int-Rn of most of the scatter points was greater than 1.0. Such results indicate that Int-Rn grew substantially stronger, and that long-distance accessibility increased during the modernization period.

Table 2-1 Parameter comparison of Fig.7 and Fig.8

	1902, Kyoto	2020, Kyoto	1949, Xi'an	2019, Xi'an
Regression Line	y=1.87x+0.46	y=1.45x+0.42	y=1.91x+1.02	y=1.73x+0.80
Intelligibility(R2)	0.81	0.93	0.82	0.85
Global Int-Rn(mean)	1.38	2.12	1.71	1.91
Local Int-R3(mean)	2.12	2.66	2.24	2.49

Table 2-1 gives key parameters of the scatter plots in Fig. 2-7 and Fig. 2-8 of particular note is the slope of the regression line fitted to the Xi'an (Fig. 2-7) scatter points, which decreases from 1.905 in 1949 to 1.725 in 2019. The slope of the regression line for the Kyoto scatter diagrams (Fig. 2-8) also decreases, from 1.868 in 1902 to 1.454 in 2020. The fact that the slopes decrease means that the scatter points move rightward (i.e., Int-Rn becomes stronger). In general, urban networks with a higher Int-Rn are better suited for long-range accessibility, since Int-Rn is calculated with up to all topological depths in Depthmap and is closely related to motor vehicle traffic. In contrast, urban networks with a higher Int-R3 are better suited for short-range accessibility related to pedestrian traffic. From the basic of these, it can be inferred that the modernization of the two cities was heading toward motorization.

The intelligibility (R^2) value for Xi'an increased from 0.8229 (1949) to 0.8509 (2019), while the value for Kyoto increased from 0.8054 (1902) to 0.9319 (2020). Hillier suggests that intelligibility is used to describe the correlation between local integration and global integration and measures whether the local space and the global space environment is related and unified. This relationship presents if an area is intelligible in its global context (Hillier, 1987).

Hillier also suggests that if the intelligibility value of local space is low, the implication is that the local centrality of the regional urban space cannot be integrated with the global space and is thus relatively isolated (Hillier, 1993). The value of intelligibility (R^2) increases in both Xi'an and Kyoto, meaning that the solidarity of the respective regions has increased during the modernization process.

2.4 Conclusions

In this Chapter, we analyzed of urban spatial structure changes during the process of modernization in historical cities, focusing on historical capital cities, Xi'an and Kyoto. And then we investigated the evolution of the morphological characteristics of the typical walking space from the street structures and network systems perspective, and examine the shift in the topological relationship between historic block space and urban whole space.

The analysis produced three important findings:

1. With the expansion of the urban area, the topological centers changed correspondingly. The topological center in the main urban area of Kyoto clearly expanded outward from 1902 to 2020 in both the horizontal and vertical directions

simultaneously. In Xi'an, the area expanded from one topological center centered on the bell tower in 1949 to two topological centers in 2019. Int-Rn increased markedly for the two cities (especially for Kyoto), and long-distance accessibility increased during the period of modernization. The implication is that the modernization of the two cities was heading toward motorization.

2. The average Int-Rn change rates of the local historical blocks in the old Xi'an city show a difference in the local change and the global growth of its urban space, and make evident the local development feature of block evolution. On the other hand, it is found that the Int-Rn change rates for the three wards in Kyoto are similar to the global change rate, indicating a consistent change in global integration and a strong consistency of global street construction. The local integration will be further described as macro factor in the next chapter about walkability, since local integration could reflect local accessibility that is more related to walkability.

3. The global and local integration correlation of the two major urban areas is reinforced by the characteristic curve and index analysis, with the two exhibiting strong similarity. If the intelligibility (R^2) value of local space is low, the indication is that the local centrality of the regional urban space cannot be integrated with the global space and is thus relatively isolated.

In this study, the intelligibility (R^2) value increases in both Xi'an and Kyoto, meaning that the solidarity of the respective regions has increased during the modernization process.

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CHAPTER 3

The comprehensive evaluation of the walkability in historical capital cities: the case of Xi'an and Kyoto

3.1 Introduction

The main purpose of this chapter is to identify the inherited problem of historical cities regarding walkability using a comprehensive set of evaluative factors that tend to either improve or hinder the walking environment in the historical central districts of such cities. Given the similarities in their history and the urban form of their historical central areas, the cities of Xi'an and Kyoto were selected as appropriate case studies.

Various measures to assess the walkability of an area have been used in previous research. A walkability index typically reflects the ability to perform errands on foot from a residential location (Walkscore, 2022). Broadly speaking, the concept of "walkability" is concerned with the quality of accessibility as a platform for daily life based on pedestrian mobility (Campisi, 2019). In order to solve the increasingly serious connectivity and accessibility problems of pedestrian movement, it is especially important to address the fragmentation of pedestrian networks and the difficulties in mediating the co-existence of automobiles and pedestrians resulting from automobile-oriented urban development.

In this chapter we consider two different spatial scales for walkability assessment: the macro scale and the micro scale. Macro-scale quantitative evaluation of walkability is primarily based on geographic information system (GIS) measurements ranging from a citywide scale to a neighborhood scale. Indicators related to urban form characteristics (e.g., intersection density, street connectivity, proximity to transit stops and urban amenities, and diversity of land use) are often used for the walkability assessment at the macro level. From among these indicators, we chose to adopt the physical quantitative indicators measuring the connectivity and accessibility related to street structure using Space Syntax. Space Syntax is a common tool for evaluating the accessibility and connectivity of a space simply from its spatial geometric form (topological angle).

Although an axial map can effectively show the connectivity at a city-wide scale as a means to show the street structure as it affects pedestrian movement (macro scale), detailed characteristics of specific streetscapes should also be examined to show the built environment that tends to influence daily human activities and pedestrian movement. Thus, we judged it important to combine a micro-scale evaluation of such streetscapes (e.g., sidewalk conditions, street traffic) with a macro-scale assessment of street connectivity (Ewing, 2009). In particular, because of their grid-based urban structure, many Asian historical cities have their own special street view styles (e.g., architectural style and townscape and street layout). Furthermore, in today's Asian cities, many mixed-use and walkable streets have inherited specific features of the old city (Kato,2020) and their historical blocks often have unique and attractive cultural and commercial shops (Cui, 2015). Thus, a specific evaluation of walkability at the street level in historical blocks is needed. In this study micro-scale walkability entails the use of indicators that capture detailed characteristics of the built environment at the street level, as noted earlier, our ultimate aim is to identify improvement areas in the historical built environment that will promote and facilitate walking activities as part of an overall effort to create a pedestrian-friendly city.

3.2. Literature review

3.2.1. Existing indicators for micro-scale walkability

Insofar as chapter 2 presented detailed information on the macro-level evaluation of street connectivity using Space Syntax, our focus in this section is on reviewing the previous literature related to indicators for the assessment of walkability on the micro scale (i.e., at street level).

To develop the indictors for walkability assessment and create the audit checklist that we applied to our case studies, we first reviewed some of the available audit tools. Clifton et al. (2007) developed the Pedestrian Environmental Data Scan (PEDS), a complete audit for evaluating a walking environment that has been used by academics in the field of transportation and physical activity research, as well as by practitioners seeking an assessment tool for prioritizing investments in public spaces. Sallis et al. (2015) developed and evaluated a brief audit instrument that quantifies modifiable attributes of environments which can be easily used by practitioners. From the 120-item Microscale Audit of Pedestrian Streetscapes (MAPS) measure of street design, sidewalks, and street crossings, they created a 15-item version (MAPS-Mini) on the basis of associations with physical activity and attribute modifiability. Maleki et al. (2014) identified the differences in built environment features across diverse communities and their impact on people's health. They constructed the Wisconsin Assessment of the Social and Built Environment (WASABE) as an addition to a statewide household-based health examination survey, the Survey of the Health of Wisconsin (SHOW), to objectively measure participant neighborhoods. We found that while these prior studies address the use of comprehensive evaluations covering many aspects related to the built environment of Western or European countries, the specific characteristics of urban areas in Asian countries are not necessarily considered.

With regard to the Asian context (Cerin, 2011; Hanibuchi, 2019), an objective assessment of the micro streetscape pedestrian environment has been validated by using streetscape elements such as crowdedness on streets and the presence of man-made obstacles. Cerin et al. (2011) developed an audit tool (EAST-HK) to objectively assess aspects of the neighborhood environment that may affect walking in Hong Kong and similar ultra-dense Asian metropolises, including 91 items designed to capture the four main built-environment multidimensional themes of functionality, safety, aesthetics and destinations. Hanibuchi et al. (2019) simplified Cerin's audit tool and examined the indicators for virtual auditing; their three aspects—physical conditions, safety, and aesthetics—basically corresponded to the themes of EAST-HK (Cerin, 2011). The authors used indicators for measuring objective aspects of the walkability such as sidewalk width, the amount of vegetation, and road traffic.

It has been widely discussed by previous authors that walkability is not only affected by various objective elements, but also by the subjective perception of individuals who walk certain streets or routes (De Vos, 2022). Thus, we reviewed some of the key literature on perceived walkability, with an emphasis on the determinants and effects of perceived walkability and how it relates to objective walkability (Van Dyck, 2013; Otsuka, 2021; Van der Vlugt, 2022; Oreskovic, 2014). The key indicators frequently used in the previous literature include building environment characteristics such as street furniture and pavement, as well as perceived suitability and ease of walking. Using photographs, Oreskovic et al. (2014) concluded that perceived walkability is mainly affected by the building environment and street view; specifically, based on the presence of building windows, focal points, pedestrians, and cars. Van der Vlugt et al. (2022) used a structural equation modeling (SEM) approach to investigate the relations among travel attitudes, socio-demographic factors, objective walking accessibility, perceived walking accessibility and realized walking behavior. Otsuka et al. (2021) found that walkability is strongly influenced not only by the built environment structure as it affects walking distance to destinations, but also by micro-scale detailed elements such as the quality of the pavement, the presence and nature of street furniture, and the presence of trees and greenery. It is evident from such previous research that walking (frequency and duration) is not only affected by objective elements, but also by the subjective quality of an area and the perceived suitability and ease of walking.

In addition, articles focused on the characteristics and walkability of specific historical blocks and the traditional aspect have also appeared (Li, 2020; Yin, 2021). Li (2020) discussed walkability in historic cities/ urban spaces and noted that historical cities have assets that possess both cultural and economic value. Yin et al (2021) used the historical city of Xi'an as an example and found that perceived walkability positively affects life satisfaction, both directly and indirectly, through travel satisfaction. Both articles (Li, 2020 and Yin, 2021) recognize the importance and uniqueness of perceived walkability as it relates to the built environment in historical cities.

Based on our review of the literature, we selected a limited number of evaluation items that had been frequently used in prior audits and that could play a significant role in assessing, on a micro-scale, the walkability of historical cities such as Xi'an and Kyoto. The following are the ten items that we selected:

1) Well-maintained built environment (no decrepit infrastructure or abandoned buildings)
2) Well-designed build environment (beautiful/ aesthetic)

3) Clean and tidy built environment
4) Obstacle-free built environment
5) Attractive and lively built environment (presence of commercial and lively stores)
6) Traditional streetscapes/preservation of historical buildings
7) Sidewalk
8) Vegetation
9) People
10) Vehicular traffic (i.e., four-wheel vehicles only)

3.2.2. Determination of evaluation item for walkability

We divided the micro-level indicators for walkability into two categories perceived indicators and objective indicators and used both the perceived and objective evaluation indicators of street views and their descriptions in our case studies. Table 3-1 lists the indicators and the previous studies in which they were used.

3.2.2.1. Perceived walkability evaluation indicators

Urban design includes the arrangement and appearance of built and natural features in a community (e.g., landscaping and building architecture); the transportation system encompasses facilities, infrastructure and services that link locations. All of these dimensions of the built environment have been found to be related to physical activity (Cerin, 2011); it has also been found that people's perceptions can be influenced by such physical characteristics in urban areas. Perceived walkability is principally affected by the building environment and street view (Oreskovic, 2014). For our study, we identified six main indictors to assess perceived walkability:

1) A Well-maintained built environment is a basic condition affecting the way people perceive their walking routes (Clifton, 2007; Pikora, 2006) The indicator of well-maintained built environment includes two main aspects: the presence of decrepit infrastructure (seats, garbage cans, snacks, poles, fences, pipes, walls, etc.) and structures such as those that are abandoned or under construction that can be judged by their appearance.

2) A Well-designed built environment is the aesthetic aspect (Cerin, 2011; Sallis, 2015) and is judged by the beauty/ugliness of the street view.

3) Cleanliness is a notable for multiple aspects of the pedestrian environment (Hanibuchi, 2019; Clifton, 2007). The cleanliness of the built environment can be evaluated based on the presence of litter, garbage, broken glass, etc.

4) An obstacle-free street is an important factor affecting walking. Sidewalk obstructions are undesirable since they reduce the amount of walking space available and force pedestrians to take detours (Cerin, 2011; Hanibuchi, 2019). Here, obstacles are mainly evaluated based on whether a large number of bicycles (or two-wheeled electric vehicles), uneven pavement, or signboards that affect walking are found along the road.

5) An Attractive and lively built environment refers to the aesthetic and commercial aspects of a street (Cerin, 2011; Sallis, 2015). The presence of interesting stores is evaluated as a main characteristic of a historical district and can play a significant part

in forming an attractive and lively built environment.

Table 3-1. Review of specific perceived and objective evaluation indicators of street scenes

		1	2	3	4	5	6	7	8	9	10	11	12
Perceived evaluation indicators		Hanibuchi et al, 2019	Clifton et al, 2007	Cerin et al, 2011	Oreskovic et al, 2014	Li et al, 2020	Van Dyck et al, 2013	Sallis et al, 2015	Maleki et al, 2014	Yin et al, 2021	Van der Vlugt et al, 2022	Otsuka N. et al, 2021	De Vos et al, 2022
1	**Well-maintained built environment (no presence of decrepit infrastructure abandoned buildings)**		◎	◎			◎		◎	◎	◎	◎	◎
2	**Well-designed build environment (beautiful/ aesthetic)**	◎		◎	◎				◎				◎
3	**Clean and tidy built environment**	◎	◎	◎				◎					◎
4	**Obstacle-free built environment**	◎	◎	◎			◎				◎		◎
5	**Attractive and lively built environment (presence of commercial and attractive shops)**	◎		◎				◎	◎				◎
6	**Traditional streetscapes/preservation of historic buildings**					◎							
Objective evaluation indicators													
7	**Sidewalk**	◎	◎	◎				◎	◎				
8	**Vegetation**	◎		◎				◎	◎			◎	
9	**People**	◎		◎	◎				◎				
10	**Vehicular traffic**	◎	◎	◎	◎		◎		◎		◎		

6) Traditional streetscapes and the preservation of historic buildings are crucial to the evaluation as these factors can have a strong influence on people's perceptions. The characteristics of an area, such as streetscapes, building appearance, and the identity of the area, especially in a city's historical blocks, have begun to appear in the discourse on urban planning, environmental psychology, and tourism management, with a focus on the tie between people and place (Li, 2020; Proshansky, 1978). The conservation of old cities can be regarded as part of a region's cultural heritage, seen within the context

of modern urbanization. Historical cities have assets that have both cultural and economic value (Lhc-s, 2022). Thus, because these factors have a strong influence on people's perception, the evaluation of traditional streetscapes/preservation of historic buildings is an important piece of the evaluation puzzle.

3.2.2.2. Objective walkability evaluation indicators

The four objective walkability indicators used in this study include sidewalk/mixed road, vegetation, vehicular traffic/cars, and people flow. Importantly, these factors are not part of the above list of perceived indicators.

The presence of a Sidewalk has been associated with directness of walking routes and an influence on the levels of physical activity (Hanibuchi, 2019; Malecki, 2014). Sidewalks are delineated from road by something other than just marking, such as curbs or poles (which may be minor). They are often higher than the surrounding road and proceed along the sides of the road (Cordts, 2016).

8) Vegetation as a neighborhood characteristic is a positive aesthetic evaluation element and a micro-scale detailed element affecting walking. Vegetation includes trees, hedges, and all types of vertical vegetation on both sides of a road or beside a building (Sallis, 2015; Otsuka, 2021).

9) The presence of People on the street is used as an indicator in the evaluation since it shows effective movement and active transportation across the environment (Cerin, 2011; Malecki, 2014). Good people flow/passage is based on the presence of people.

10) Vehicular traffic is used as an indicator as such traffic prevents the safe and effective movement of people through the environment (Oreskovic, 2014; Malecki, 2014). Four-wheeled vehicles are included to assess traffic flow.

Using the six perceived indicators and four objective indicators, we developed a simple checklist to measure micro-scale walkability. Based on street view pictures, an evaluation was made by determining the indicator scores for the selected areas in Xi'an and Kyoto. Taken together, the above ten indicators were the basis for calculating our Walkability Evaluation Scores (WES).

3.3. Materials and methods

Assessment procedure includes six steps in turn, determining case study area, selection of site points and street view images, perceived walkability evaluation, objective walkability evaluation, micro evaluation (combing the perceived and objective indicators) and adding macro-scale evaluation indicators of walkability (Data Flow as below).

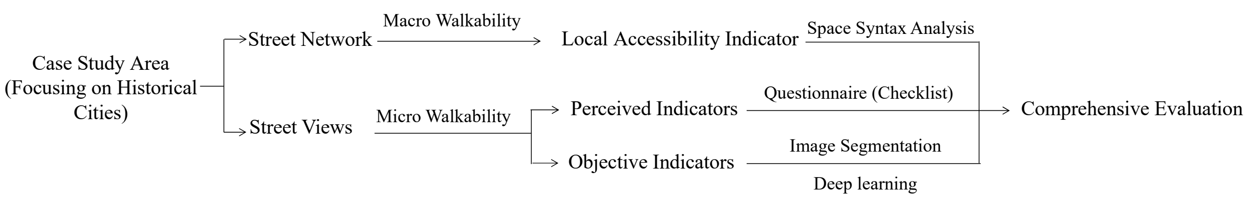

Fig. 3-1. Data Flow

3.3.1. Case study area

The historical core districts in the two selected cities served as our research targets. The main urban area of Xi'an contains the old urban blocks within the city walls. An area of 1.5 x 2.5 square kilometers that includes the Beiyuanmen and Sanxue Street historical block was selected for evaluation (Fig. 3-2). In Kyoto, the city center area (Shimogyo Ward, Nakagyo Ward and Higashiyama Ward) was the target. From this area, we selected the "Tanoji area," and the "Gion block", comprising a total of 1.6 x 2.3 square kilometers (Fig. 3-3).

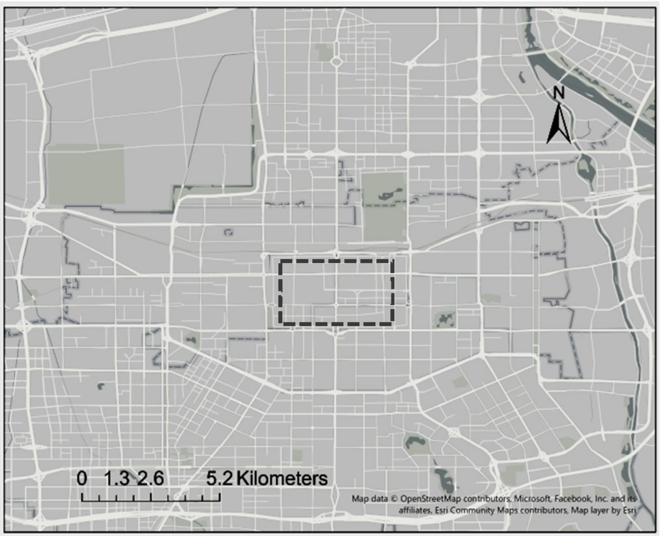

Fig. 3-2. Research Area in Xian (ArcGIS map)

It should be noted that the selected area in each city includes two distinctive types of areas: pedestrian-friendly historical blocks (hereafter referred to simply as historical blocks) and car-oriented modern areas (i.e., residential areas where few tourists are seen). The historical blocks in Xi'an are located in the northwest and southeast part of the old city area within the city wall; the northeast and southwest areas are the modern sections. The historical block in Kyoto is located on the east side of the selected area; the modern section is on the west side.

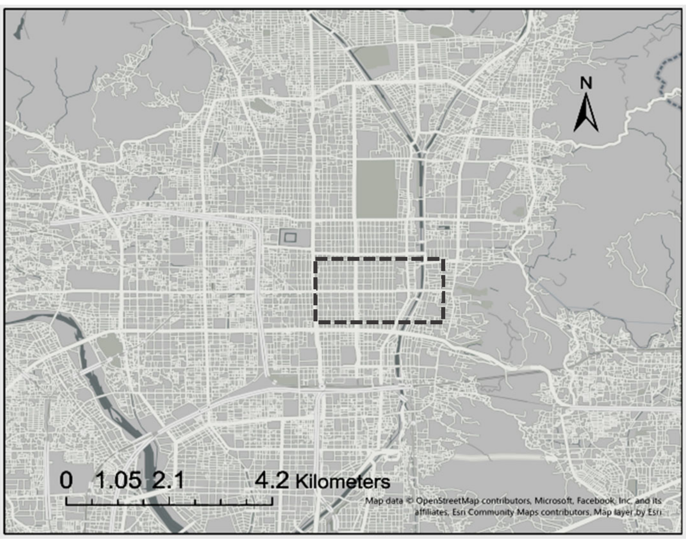

Fig. 3-3. Research Area in Kyoto (ArcGIS map)

3.3.2. Selection of site points and street view images

In order to examine walkability on the micro scale, we obtained street view images using API (Application Programming Interface) data from Google and Baidu (the photos were taken in the spring of 2019). The longitude and latitude of the intersections (crossroads) in the research areas were first confirmed with ArcGIS, after which the angle of each intersection, in four directions, was calculated, and the street views were downloaded using the API. It should be noted that the photos used from both areas are street views collected by Google and Baidu over a period of time, so it was not possible to identify the specific time information of a specific street view. For example, we could not determine the specific time of image acquisition or whether the image was taken on a weekday or a weekend.

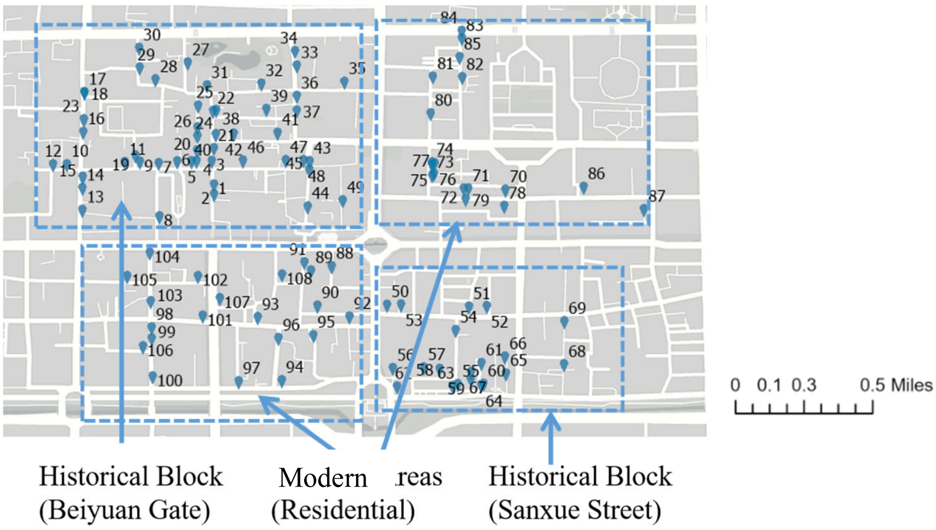

Fig. 3-4. Selecting street view points in Xian (108 points including 69 historical block points) (ArcGIS map)

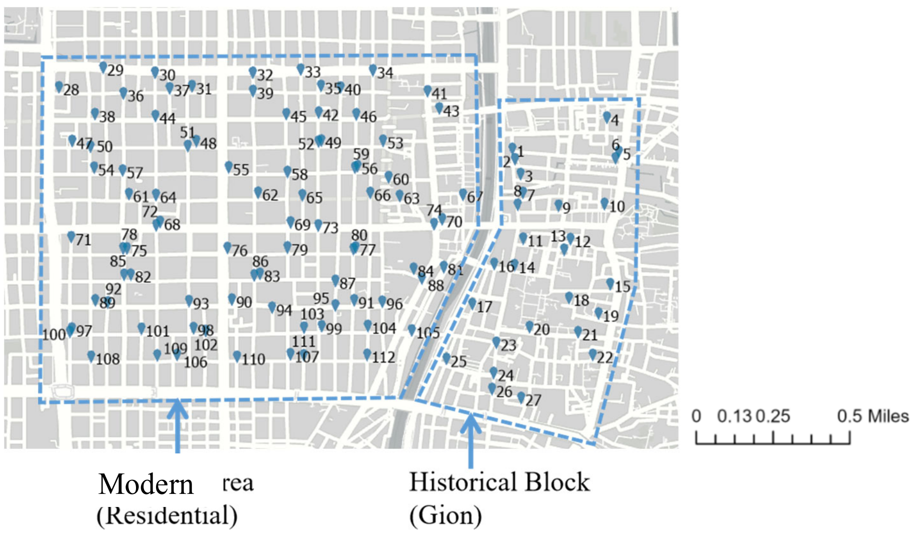

Fig. 3-5. Selecting street view points in Kyoto (112 points including 27 historical block points) (ArcGIS map)

To ensure consistency in the visual street angle of the downloaded images, the horizontal direction of the street was determined by longitude and latitude; the vertical focus used the end (vanishing point) of the road as the midpoint. A quartering method was used to choose 108 view points from a total of 430 Xi'an street views (Fig. 3-4) and 112 view points from a total of 450 Kyoto street views in all directions for each intersection (Fig. 3-5).

3.3.3. Perceived walkability: using Google Forms to record the perceived evaluation indicators (from Q1 to Q6)

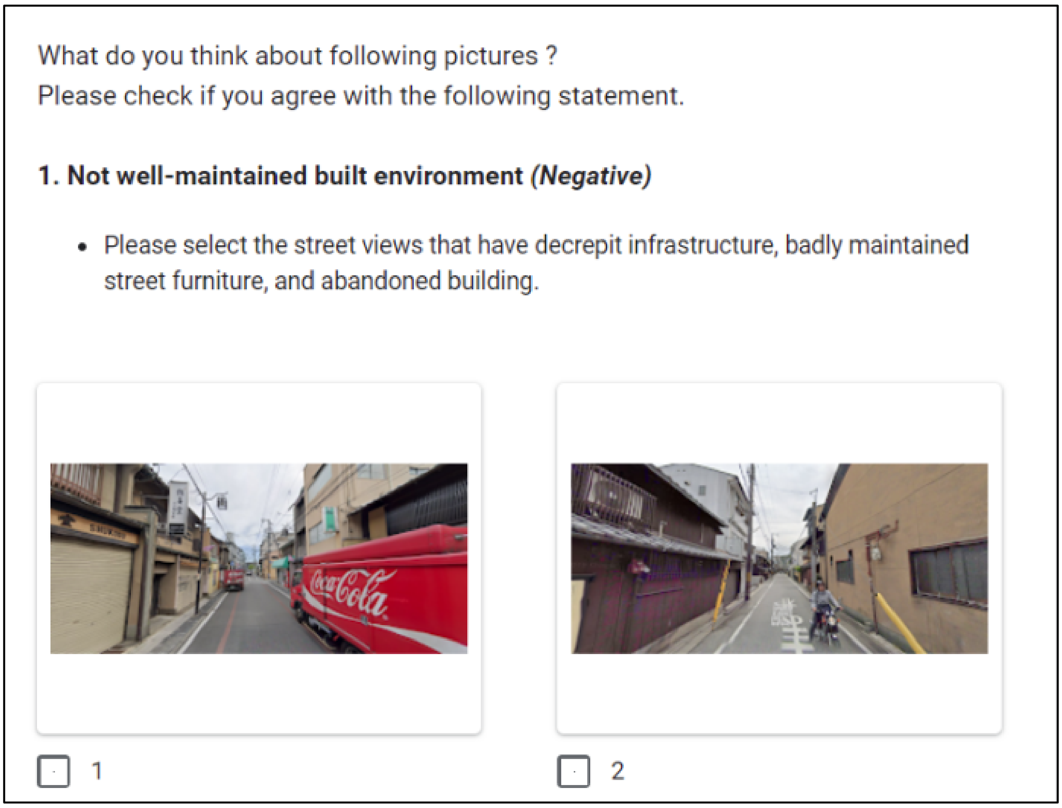

Fig. 3-6. Example of the questionnaire using Google Forms

Evaluation of the "perceived assessment" of walkability for the selected street views was carried out by auditors using the six perceived evaluation indicators developed for the study (Table 3-1, Q1-6). The forms used in the evaluations were created on Google Forms (Fig. 3-6). Statements regarding the six items on the walkability checklist were presented to the auditors; for each statement, the auditor was shown street view pictures from Xi'an and Kyoto. From the first to the final picture, the auditors were asked to choose either the positive or negative evaluation option on the Google form according to the six questionnaire prompts, and to complete the procedure for all six indicators for every picture.

The WES assessments for Xi'an were made by 10 evaluation auditors (8 males and 2 females). For Kyoto, the assessments were made by 13 evaluation auditors (10 males and 3 females). The auditors were students at Osaka University in their twenties or thirties, as well as members of the staff at the University. The auditors had a related background in the subject area, as all belonged to the Department of Engineering, with a specialization in architecture (Table 3-2).

During their assessments, the auditors independently conducted audits of all the street view pictures, using Google Form to record their responses. The research team provided the auditors with clear instructions for the scoring of items on the walkability checklist. The image evaluations were performed for all selected points to determine the score for each indicator and each street view.

Table 3-2. List of Auditors

City	Date of assessment	Name	Age	Gender	Nationality
Xi'an	14-Dec-2022	A	20s	Male	China
	15-Dec-2022	B	20s	Female	China
	15-Dec-2022	C	60s	Male	Japan
	16-Dec-2022	D	20s	Male	Japan
	20-Dec-2022	E	20s	Male	Japan
	20-Dec-2022	F	20s	Male	Japan
	20-Dec-2022	G	40s	Female	Japan
	21-Dec-2022	H	30s	Male	Japan
	21-Dec-2022	I	20s	Male	Japan
	21-Dec-2022	J	20s	Male	Japan
Kyoto	14-Dec-2022	A	20s	Male	China
	15-Dec-2022	K	20s	Female	French
	15-Dec-2022	B	20s	Female	China
	16-Dec-2022	D	20s	Male	Japan
	16-Dec-2022	C	60s	Male	Japan
	19-Dec-2022	L	20s	Male	Japan
	20-Dec-2022	E	20s	Male	Japan
	20-Dec-2022	G	40s	Female	Japan
	20-Dec-2022	F	20s	Male	Japan
	20-Dec-2022	M	20s	Male	Japan
	21-Dec-2022	H	30s	Male	Japan
	21-Dec-2022	I	20s	Male	Japan
	21-Dec-2022	J	20s	Male	Japan

3.3.4. Objective walkability: using the percentage of street components by the image segmentation method for the objective evaluation indicators (Q7 to Q10)

The objective assessment of walkability in WES used the percentage of street components (roads, trees, etc.) (Table 3-1, Q7- 10) automatically identified by an image segmentation method based on deep learning (DL). In particular, this study employed the DeepLab V3+ model, which applies an Encoder-Decoder with Atrous Separable Convolution for Semantic Image Segmentation (Chen, 2018). This is extended for DeepLabv3 to include a simple yet effective decoder module to refine the segmentation results, especially along object boundaries.

We used the top performing DeepLab V3+ model trained on the Cityscapes dataset (Cordts, 2016) named xception71_dpc_cityscapes_trainval, with a Cityscapes mIOU (Model evaluation index: Mean Intersection over Union) of 82.66%.

The Cityscapes dataset is an image dataset with an annotation of streetscape segments. The annotation is defined for 30 classes based on seven groups of streetscape components (ground, human, vehicle, building, infrastructure, nature, and sky), which were modified from the Cityscapes class definitions. The dataset provides 19 classes for training (road, sidewalk, building, wall, fence, pole, traffic light, traffic sign, vegetation, terrain, sky, person, rider, car, truck, bus, train, motorcycle, and bicycle); the other 11 classes, such as bridge and pole ground, were excluded from the dataset due to the rarity of their appearance in the streetscapes (Cordts, 2016). Every pixel in all the street view images was classified into one of 19 segments by DeepLab V3+.

It should be noted that there is an error associated with recognition by the model itself (DL), which requires training and optimization of model elements. In this study, the extraction percentage of segmented elements involves an error due to the difficulty of effectively extracting the color edges of the different elements. The average overall extraction percentage was 91.6% and 87.4% in Xi'an and Kyoto, respectively. For the extraction of a single image with large deviations, we developed a method for correcting the errors. First, the percentage of segments (hereafter, PSG) for each point in the selected street view images is converted automatically by a system developed by the authors using Python code. If there is an obvious error in a particular element, the obtained segmentation image is subjected to analysis in Adobe Photoshop, where the percentage of the entire picture (i.e., the area of all color pixels) occupied by the element (i.e., the area of its color pixels) is determined. A comparison with the original street view is then made and the percentage of the incorrect element is adjusted to the correct classification.

Based on the above steps, we completed image segmentation of all the street views with the same angle for the 108 selected points in Xi'an and the 112 selected points in Kyoto. Figs.3-7 and 8 show examples of the segmentation mapping by adding different colors corresponding to each class, such as yellow for a person or green for a bicycle.

The image was further visualized and a segmentation overlay in the appropriate colors was added onto the various regions. We used the percentage of the four objective indicators (sidewalk, vegetation, car, and people) for the evaluation, as defined in the previous section.

In order to provide a comparable value for a perceived indicator, we set 2 as the maximum PSG value for each objective indicator. For all the street views, the percentage of the street view element relative to the maximum value of the element was calculated and then converted to a score ranging from 1 to 2.

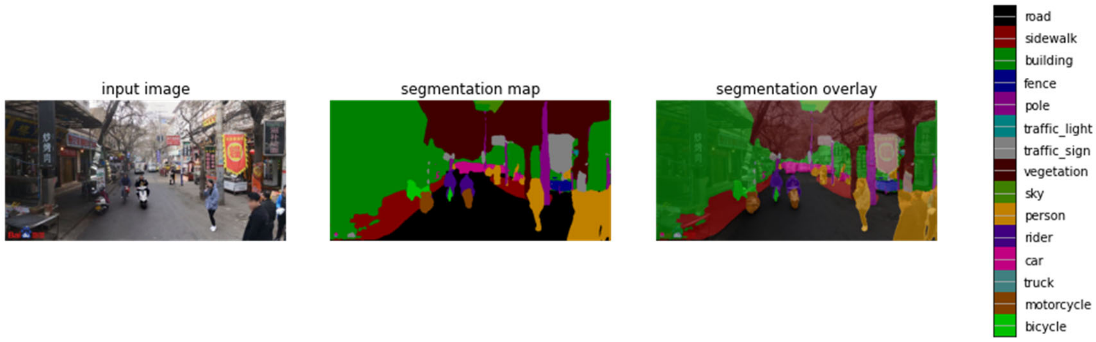

Fig. 3-7. Sample of Segmentation map in Xi'an (No. 11)

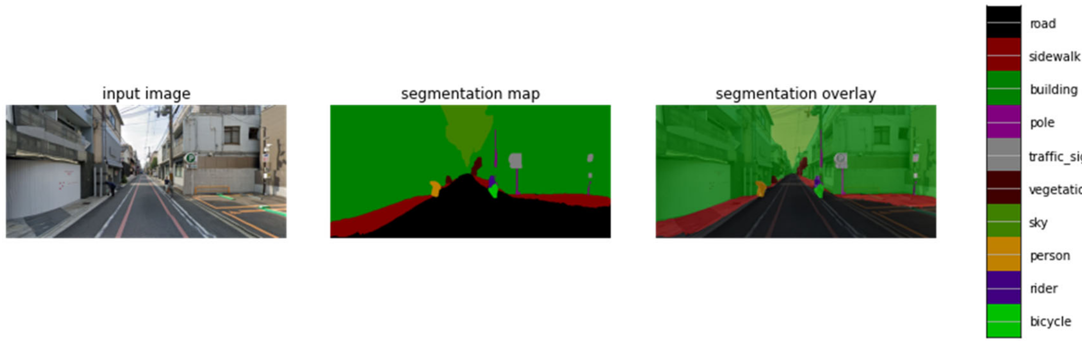

Fig. 3-8. Sample of Segmentation map in Kyoto (No. 10)

3.3.5. Micro evaluation combing the perceived (1-6) and objective (7-10) indicators

The final walkability evaluation score (WES) is based on the above walkability checklist and includes both perceived and objective evaluation scores. For the perceived indicator evaluations, if an auditor feels that a street view image corresponds well to the indicator in question, the image is assigned a score of 2 for that indicator; if the auditor feels that the image does not correspond well to the indicator, the image is assigned a score of 1 for the indicator. To produce the final score, the average value of each perceived indicator is calculated for all auditors and for all street views.

For the objective evaluations, the indicator (element of the street view) with the smallest proportion on the positive side is given a score of 1 for the image; the maximum proportion is given a score of 2. The average value for each indicator in each image is ultimately calculated. The final walkability evaluation scores ranged from 10 to 20.

3.3.6. Macro-scale walkability

For the macro quantitative evaluation of walkability, we selected the local integration value (hereafter Int-R3) as our macro indicator, based on an axial analysis from Space Syntax. Axial analysis is a way of analyzing spatial layouts represented by an axial map. In order to analyze the configuration layout of each city, we translated the actual spatial structure into an axial map, which consists of the minimum set of the longest lines drawn tangent to vertices that are visible to one another other. For our topological analysis, the axial map was projected onto a justified graph in which the axial lines are represented as nodes, and the intersecting lines are the connections between the nodes (Hillier, 1984).

Int-R3 essentially describes the “local accessibility” of an element in the study area network. The higher the value of Int-R3, the better in terms of accessibility. More specifically, the Int-R3 can be defined as the local integration values of the axial lines at radius 3 (root plus two topological steps from the root) that can be used to represent a localized picture of integration, which has been related to walkability in previous studies (Hillier, 1993; Kigawa, 2005).

3.4. Results and discussion

3.4.1. Macro: local integration (Int-R3) by space syntax

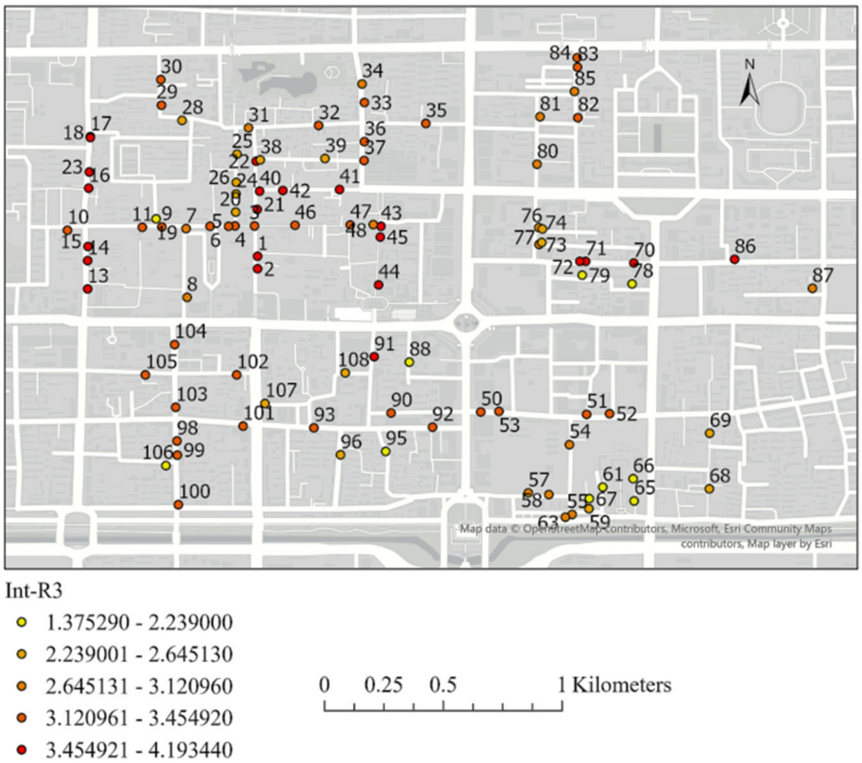

Fig. 3-9. Local Integration (Int-R3) of street view points based on axial map in Xi’an

Fig. 3-9 shows the value of Int-R3 for the street view points based on the axial map of Xi’an. As can be seen here, the points in the Beiyuan Gate historical block in the northwest corner have a relatively high Int-R3 (3.37) average; however, the average Int-R3 (2.66) in the historical block of Sanxue Street in the southeast corner is lower than that in the modern (residential) areas (3.02). Thus, it can be said that the distribution of Int-R3 within the old city shows no unified tendency.

Fig. 3-10 shows the value of Int-R3 for the street view points based on the axial map of Kyoto. As indicated, the average value of Int-R3 (3.85) for the area in the west is rather high. Moreover, the average value for the modern areas in the west is higher than that for the historical blocks in the east (2.48).

Overall, in Xi'an, the average Int-R3 in the modern areas and in its historical blocks is not very different. In contrast, Kyoto's average Int-R3 in the modern areas is higher than in its historical blocks. The general consistency of Kyoto's streets is stronger, with a clearer distinction between historical blocks and modern areas, than is the case in Xi'an. Xi'an's Int-R3 does not suggest a unified tendency inside the old fortification. The mixed results indicate that accessibility within the historical blocks varies depending on the street view points.

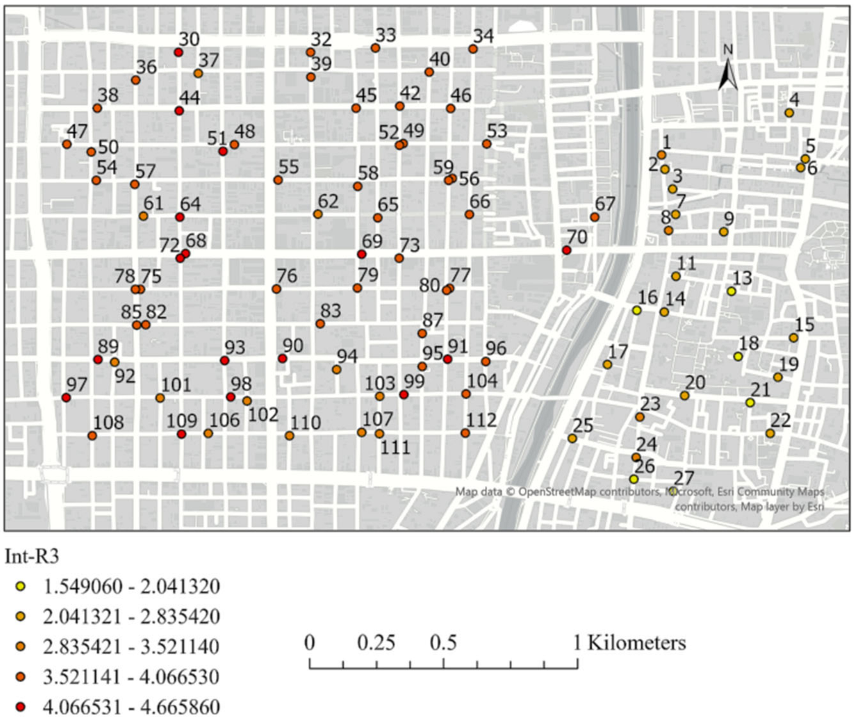

Fig. 3-10. Local Integration (Int-R3) of street view points based on axial map in Kyoto

3.4.2. Micro: walkability evaluation score

Table 3-3 shows the average walkability evaluation score (WES) for each index. As indicated by the values in the right-hand column of the table, the average of the perceived and objective evaluation scores is slightly higher for Xi'an (14.270 to 14.121).

As the table shows, the walkability evaluation scores for the two cities have their own distinctive characteristics. Specifically, in the perceived evaluation for Xi'an, only the scores for attractive and lively built environments and for traditional streetscapes are higher for the historical blocks than for the modern areas (Q5: 1.265 to 1.028, and Q6: 1.184 to 1.015). On the other hand, the basic built environment, infrastructure and traffic condition indicators, such as a well-maintained built environment, a well-designed built environment, a clean and tidy built environment and an obstacle-free built environment all have lower scores in the historical block than in the modern areas (Q1: 1.793 to 1.890, Q2: 1.858 to 1.969, Q3: 1.568 to 1.741 and Q4: 1.090 to 1.097). In the objective evaluations, the historical block is superior to the modern area in having good people flow and light vehicular traffic. However, basic elements such as sidewalk area and amount of vegetation are lower in the historical block than in the modern areas, and the total WES of the historical block is slightly lower than the total WES in the modern areas (Total Q1-Q10: 14.250 to 14.307).

In the perceived evaluation for Kyoto, the historical blocks show similar characteristics to Xi'an, with high scores for traditional streetscapes and obstacle-free built environment (Q6: 1.293 to 1.066 and Q4: 1.197 to 1.081). In addition to similar results for attractive and lively built environment and cleanness of the built environment (Q5: 1.077 to 1.082 and Q3: 1.849 to 1.841), the scores for the historical blocks are also lower than in the modern areas for well-maintained and well-designed built environments (Q1: 1.806 to 1.913 and Q2: 1.915 to 1.969). In the objective evaluation, the scores for good people flow and light vehicular traffic in the historical and modern blocks for Kyoto are comparable (Q9: 1.008 to 1.010 and Q10: 1.975 to 1.940). The historical blocks have relatively higher vegetation (Q8: 1.091 to 1.070), but the pedestrian sidewalk area is less than in the modern areas (Q7: 1.079 to 1.096). Overall, the walkability in Kyoto's historical blocks is higher than in the modern areas (Total Q1-Q10: 14.291 to 14.067).

Generally speaking, the perceived evaluation scores in Kyoto are higher than those in Xi'an, especially with respect to cleanliness and well-designed built environment. On the other hand, Xi'an is clearly superior to Kyoto in terms of having an attractive and lively built environment. As for the objective indicators, the WES values for Xi'an are generally higher than those for Kyoto, with more vegetation and better people flow as obvious advantages.

Table 3-3. Average value of walkability evaluation scores (WES) for Xian and Kyoto

Q1-Q10 / City /Block	Perceived evaluation index (build environment and traditional streetscapes), Q1-6						Objective evaluation index, Q7-10				Total score
	Q1: Well-maintained built environment	Q2: Well-designed built environment	Q3: Clean and tidy built environment	Q4: Obstacle-free built environment	Q5: Attractive and lively built environment	Q6: Traditional streetscapes	Q7: Sidewalk	Q8: Vegetation	Q9: People (Good flow/passage)	Q10: Vehicular traffic (Light traffic flow)	
Xi'an (2019)	1.828	1.898	1.631	1.093	1.180	1.123	1.214	1.367	1.106	1.833	14.270
Historical block (2019)	1.793	1.858	1.568	1.090	1.265	1.184	1.149	1.260	1.146	1.936	14.250
Modern area (2019)	1.890	1.969	1.741	1.097	1.028	1.015	1.328	1.555	1.033	1.650	14.307
Kyoto(2019)	1.887	1.956	1.843	1.109	1.081	1.121	1.092	1.075	1.009	1.948	14.121
Historical block (2019)	1.806	1.915	1.849	1.197	1.077	1.293	1.079	1.091	1.008	1.975	14.291
Modern area (2019)	1.913	1.969	1.841	1.081	1.082	1.066	1.096	1.070	1.010	1.940	14.067

3.4.3. Comparative analysis of macro and micro influencing factors in Xi'an and Kyoto

The macro factors mainly come from the integration value of Space Syntax, an indicator of street connectivity. As explained in the previous section, Int-R3 essentially shows the "accessibility" of an element in the study area network. In contrast, the micro factor is derived from the synthesis of the six perceived and four objective street view evaluation indicators, which we have called WES.

On the basis of these two special aspects concerning walkability, we can compare and analyze the difference between the macro and micro indicators in the walkability evaluation and identify the differences in results for Xi'an and Kyoto.

The distribution of the macro and micro index values for all the selected points used in WES, together with the significant explanatory variables, is discussed below.

Our analysis of the macro and micro factors also shows some differences for walkability, which is explained by the differences between Xi'an and Kyoto.

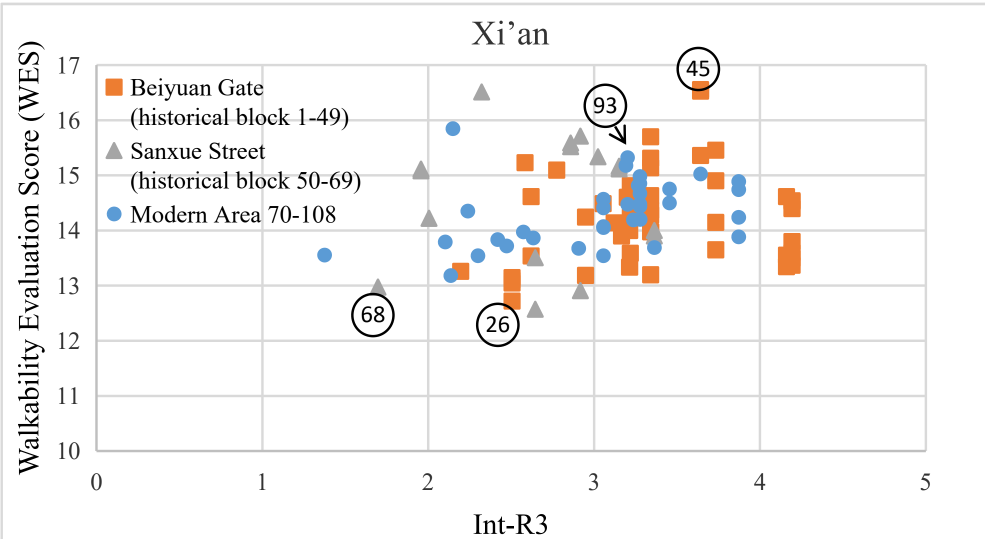

Fig. 3-11. Comparison of macro and micro indicators in Xi'an
(Numbers in circle show street view points)

Table 3-4. Correlation between Int-R3 and WES in Xi'an

Correlations

		Int-R3	WES
Int_R3	Pearson Correlation	1	.195
	Sig. (2-tailed)		.058
	N	97	95
WES	Pearson Correlation	.195	1
	Sig. (2-tailed)	.058	
	N	95	107

* Correlation is significant at the 0.05 level (2-tailed).

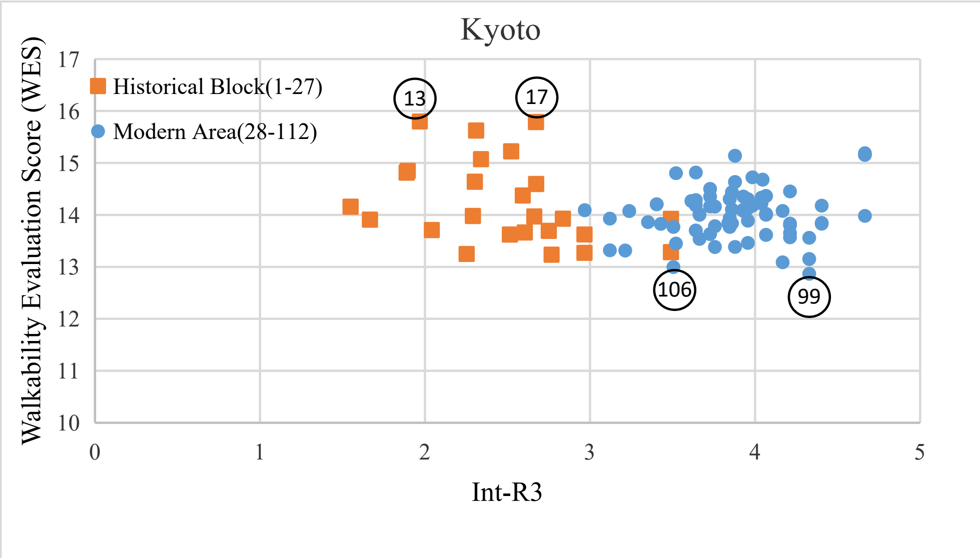

Fig. 3-12. Comparison of macro and micro indicators in Kyoto
(Numbers in circle show street view points)

Table 3-5. Correlation between Int-R3 and WES in Kyoto

Correlations

		Int-R3	WES
Int_R3	Pearson Correlation	1	-.168
	Sig. (2-tailed)		.107
	N	94	93
WES	Pearson Correlation	-.168	1
	Sig. (2-tailed)	.107	
	N	93	111

Fig. 3-11 and Fig. 3-12 are distribution diagrams for WES and Int-R3 for all the street view points in Xi'an and Kyoto, respectively. Fig. 3-11 shows clearly that the points in the historical blocks and the modern area in Xi'an present a mixed distribution and that the WES and Int-R3 values for the points have a relatively consistent positive trend. Whereas the points in the historical blocks in Kyoto are concentrated on the left side of the graph, with low Int-R3, the points in the modern blocks are distributed on the right side, with high Int-R3 (Fig. 3-12). From the distribution map of Kyoto, although road accessibility in the historical blocks is worse than in the modern areas, the specific street features are more conducive to walking, so that even in historical blocks with low Int-R3, there are points with high WES.

The Int-R3 (macro) and WES (micro) values in Xi'an and Kyoto are not at all correlated (0.058) (Table 3-4 and Table 3-5). The results show that Int-R3 (macro) and WES (micro) are independent indicators, strongly suggesting that the introduction of a micro indicator for walkability assessment (WES) has a significant meaning. Thus, it is evident that considering the micro and macro indicators together is necessary.

Table 3-6. WES for specific street view points

City	Street view point number	Perceived evaluation index (built environment and traditional streetscapes), Q1-6						Objective evaluation index, Q7-10				Total score
		Q1: Well-maintained built environment	Q2: Well-designed built environment	Q3: Clean and tidy built environment	Q4: Obstacle-free built environment	Q5: Attractive and lively built environment	Q6: Traditional streetscapes	Q7: Sidewalk	Q8: Vegetation	Q9: People (Good flow/passage)	Q10: Vehicular traffic(Light traffic flow)	
Xi'an	45	1.90	2.00	1.80	1.20	1.80	1.40	1.42	1.62	1.38	2.00	16.53
	93	1.90	2.00	2.00	1.30	1.00	1.00	1.41	1.54	1.08	1.96	15.18
	26	1.50	1.80	1.40	1.00	1.10	1.00	1.13	1.06	1.00	1.72	12.72
	68	1.50	1.70	1.30	1.00	1.00	1.10	1.18	1.00	1.03	1.77	12.57
Kyoto	13	2.00	1.85	1.92	1.85	1.23	1.92	1.00	1.02	1.00	2.00	15.80
	17	1.85	2.00	2.00	1.69	1.15	1.69	1.00	1.40	1.00	2.00	15.79
	99	1.92	2.00	1.38	1.00	1.00	1.00	1.02	1.00	1.00	1.53	12.87
	106	1.38	1.85	1.69	1.00	1.00	1.00	1.04	1.00	1.06	1.97	13.00

Table 3-6 shows the WES results (Q1 to Q10) for some representative points (No. 45, 93, 26, and 68 in Xian and No. 13, 17, 99, and 106 in Kyoto) for the points plotted in the scatter graphs in Fig. 3-11 and Fig. 3-12. Points No. 45 and 93 in Xi'an are positive example points, with high Int-R3 (macro) and high WES (micro), while No. 26 and 68 are negative example points, with low Int-R3 (macro) and low WES (micro). For Kyoto, No. 13 and 17 are positive example points, with low Int-R3 (macro) but high WES (micro), while No. 99 and 106 are negative example points, with high Int-R3 (macro) but low WES (micro). As described below, we cross-checked our results using street view images of these selected street view points.

Fig. 3-13 shows street view images of Xi'an for the selected points (No. 45, 93) plotted in the upper right corner of the scatter graph in Fig. 3-11. As noted above, the Int-R3 and WES scores are both high for the two points. Both of these positive examples have good accessibility but show different characteristics when their street view images are compared. No. 93 is located in the modern area, whereas No. 45 is located in the historical block. According to the micro indicator values in Table 6, the sidewalks for both are relatively spacious (WES-Q7: 1.42 and 1.41, respectively, for Xi'an street views No. 45 and No. 93), there is light vehicular traffic (WES-Q10: 2.0 and 1.96), and, for No. 45, there are many special cultural and food shops that attract tourists, and, thus, the score for attractive built environment is high (WES-Q5: 1.8). On the other hand, for No. 93, the score for attractive built environment is very low (WES-Q5: 1.0); however, the score for clean and tidy built environment is very high (WES-Q3: 2.0). In addition, the score for street vegetation for both street views are relatively high, especially for No. 45 (WES-Q8: 1.62) in the historical block, as trees provide ample sunshade and can protect people from the rain, meaning that people can stroll the area in their leisure time, as shown in Fig. 3-13.

In summary, for places where both the macro and micro indicators are high, the common features are relatively good accessibility, spacious sidewalks, more vegetation, and a well-maintained built environment. Moreover, it appeared that there are two types of such places: one has many attractive shops and traditional cultural street landscapes; the other is obstacle-free and has a clean and tidy built environment.

Fig. 3-13. Xi'an's street view images (No. 45/left, 93/right) plotted in Fig. 3-11

Fig. 3-14 shows street view images of Xi'an for the selected points (No. 26/left and No.68/right) plotted in the lower left corner of the scatter graph in Fig. 3-11. The Int-R3 and WES scores are both low (WES-Total: 12.7/No. 26 and 12.6/No. 68). No. 26 and 68 are located in the historic block. As shown in Fig. 14, there is too much street parking or other obstacles on the road, resulting in a minimum score for obstacle-free environment (WES-Q4: 1.0/No. 26 and 1.0/No. 68). Moreover, sidewalk space and amount of vegetation along the street scored very low (WES-Q7: 1.13/No. 26 and 1.18/No. 68, WES-Q8: 1.0/No. 26 and 1.02/No. 68). The built environment is also assessed by the auditors as not well-maintained (WES-Q1: 1.5/No. 26 and 1.5/No. 68). These are the main reasons for the poor walkability in both No. 26 and No. 68.

Fig. 3-14. Xi'an's street view images (No. 26/left, 68/right) plotted in Fig 3-11

Fig. 3-15. Kyoto's street view images (No. 13/left, No. 17/right) plotted in Fig. 3-12

Fig. 3-15 shows street view images in Kyoto for the selected points (No. 13/left and No. 17/right) plotted in the upper left section of the scatter graph in Fig. 3-12. In both cases, Int-R3 is low, but WES is high. Both points are in the historical blocks. Specifically, for the historical street (No. 13 and No. 17) on the left in Fig. 3-12, the macro indicators are lower than in the modern area, and the micro indicators are, in total, high (WES-total: 15.80/No. 13 and 15.79/No. 17). The traditional features of these points can be seen in the street views, which explains why the scores for traditional streetscapes were high (WES-Q6: 1.92/No. 13 and 1.69/No. 17). A high standard of cleanness and an obstacle-free built environment are also evident in the street views and are the reasons for the high micro evaluation scores (WES-Q3:1.92/No. 13 and 2.00/No. 17, WES-Q4: 1.85/No. 13 and 1.69/No. 17).

To summarize, in cases where the micro indicator scores are high but the macro indicator scores are low, it was found that traditional cultural street landscapes and clean and a tidy built environment were common features. On the other hand, poor accessibility in a fragmented street network with many obstacles, no spacious sidewalks, and less vegetation were problems.

Fig. 3-16. Kyoto's street view images (No. 99/left, No.106/right) plotted in Fig 3-12

Fig. 3-16 shows street view images at selected points (No. 99/left and No. 106/right) plotted in the lower right of the scatter graph in Fig. 3-12. Both points are in the modern area, with a high Int-R3 and a low WES. The total WES values are very low for both images (WES-total: 12.87/No. 99 and 13.00/No. 106). As can be seen, the sidewalks are relatively narrow (WES-Q7: 1.02/No99 and 1.04/No106) and the scores for traffic flow (WES-Q10: 1.53/No. 99 and 1.97/No. 106) and obstacles (WES-Q4: 1.0/No. 99 and 1.0/No. 106) are low. The scores for well-maintained built environment (WES-Q1: especially 1.38/No. 106) and amount of vegetation (WES-Q8: 1.0/No. 99 and 1.0/No. 106) are also low.

In summary, for cases in which the macro indicator score is high but the micro indicator scores are low, we found that very good accessibility and a well-maintained built environment were common features. On the other hand, lacking spacious sidewalks and having many obstacles, less vegetation, and lacking a lively built environment were problems.

The main distinction between Kyoto and Xi'an is that the macro indicator (Int-R3) and micro indicator (WES) scores differ substantially in the two cities (Fig. 3-11 and 3-12). Kyoto is more modernized along many of its streets (Yuan 2022), which is evidenced by its Int-R3 result. The streets of Kyoto tend to have a high Int-R3 in the modern areas; the average Int-R3 in Xi'an is not as high, meaning that overall accessibility is lower than in Kyoto. However, in walkability as evaluated by WES, Xi'an scores higher than Kyoto due to specific walking environment micro indicators. In Xi'an's historical block, where the Int-R3 is high, cars are prohibited from entering the pedestrian streets, making the environment conducive to walking. In addition, local traditional streetscapes attract tourists, as does the presence of many shops, which also creates a good atmosphere for walking.

In Kyoto, in this era of rapid modernization and a car-centered life, many of the streets have been widened, rendering Kyoto's walkable areas more fragmented, with clear differences between the historical blocks and the modern areas.

In Xi'an, there has been less fragmentation caused by modernization and, according to our WES results, the city appears to be more walkable than Kyoto. Such factors as the attraction of local characteristics and shops, and the vitality and lively atmosphere of the block lead to a large number of people being on the streets. However, Xi'an also faces severe problems with the quality of its built environment, such as lack of maintenance and conflict between the people and vehicle traffic flow.

3.5. Discussion and conclusion

As part of our exploration of pedestrian-friendly city planning, we first reviewed existing research to find suitable indicators for evaluating the walkability of historical Asian cities. Our ultimate aim was to identify specific improvements that would promote walking activities in historical building environments. We then used a checklist based on the selected indicators to evaluate walkability in Xi'an and Kyoto and identified key factors that improve or hinder the walking environment in the historic central districts of the two cities. The following are the key finding of the study:

To produce an appropriate tool for assessing walkability in such historical cities, we found that combining macro-scale indicators that measure accessibility in the street structure with micro-scale indicators for the built environment pertaining to daily human activities and pedestrian movement at the street-level is highly important. These two types of indicators were found to be independent of one another, with no obvious correlation. It suggests that the introduction of a micro indicator for walkability assessment (WES) has a significant meaning. Thus, it is evident that considering the micro and macro indicators together is necessary.

Based on an analysis of street attribute values from Space Syntax, the overall consistency of Kyoto's streets was found to be stronger than in the case for Xi'an, with clear distinctive tendencies separating the historical blocks and modern areas. Xi'an's Int-R3 values reveal no unified tendency inside of Xian's old fortification, with mixed results overall. In Kyoto, the average value of Int-R3 in the modern areas was found to be higher than in its historical blocks. In contrast, Xi'an's average Int-R3 in its modern areas was similar to the average Int-R3 in its historical block. Based on these differences in street accessibility, we examined the objective and perceived walkability factors from a micro, street-level perspective.

Comparing the walkability evaluation scores (WES) for the two cities, we found that the average overall perceived and objective scores for walkability in Xi'an were slightly higher than in Kyoto. While Kyoto had a higher perceived evaluation in cleanliness, maintenance level and design of the built environment, Xi'an was clearly superior to Kyoto in terms of attractive and lively built environment. Xi'an scored higher in the objective evaluation, with sidewalk, vegetation, and people flow as obvious advantages. The only exception was the large number of vehicles on Xi'an's streets, which hinders traffic flow and adversely affects walking.

Although both historical cities are based on a similar urban structure, many of the streets in Kyoto are more modernized than those in Xi'an. The wider streets of Kyoto tend to produce high Int-R3 in the city's modern areas due to their recent, car-oriented development. Walkability in Xi'an was found to be better than in Kyoto based on higher scores for specific walking environment factors as assessed by the micro indicators of perceived walkability.

Xi'an's development process produced less fragmentation between districts and a more walkable environment, owing to the attraction of its local character and shops and the vitality of its urban block, which have led to the creation of a lively walking environment for a large number of people. However, Xi'an is not without areas for improvement, with factors such as a less well-maintained and untidy built environment being judged as major drawbacks. Furthermore, there is an urgent need in Xi'an to establish a system for coping with the conflict between people flow and vehicle traffic.

In cases where both the macro and micro indicator scores are comparatively high, places with good walkability in the two historical cities have several factors in common, including good accessibility, spacious sidewalks and more vegetation, and a well-maintained built environment. It also appears that there are two types of walkable areas: one that has numerous attractive shops and traditional cultural street landscapes, while the other is obstacle-free and has a clean and tidy built environment.

In cases where the macro indicators are high, but the micro indicators are low, it was found that the common factors include very good accessibility in the modern area and a well-maintained built environment. On the negative side, such places lack spacious sidewalks and have many obstacles, less vegetation, and a less-than-lively built environment. In cases where the macro indicators are low, but the micro indicators are high, it was found that such places have traditional cultural street landscapes and a clean and tidy built environment in common. They also share the same problems, including poor accessibility in a fragmented street network and many obstacles, no spacious sidewalks, and less vegetation.

Our results indicate that combining factors at the macro and micro spatial levels is the key to improving the walkability of historic cities. The Institute for Transportation and Development Policy (ITDP, 2018), Al-Hagla (2009) and Rebecchi et al. (2019) also attempted to develop different indicators for assessing macro and micro aspects of walkability. They used these two types of indicators separately for the purpose of comparing the walkability of a number of cities and neighborhoods (ITDP, 2018), or different areas in the same state of development in a particular city (Rebecchi et al., 2019). However, they were different to us, their goal was not to assess walkability in a holistic way by combining the two different spatial levels. Also, their quantitative evaluations mainly focused on macro indicators based on GIS attributes such as land use and usage density, and micro evaluations based mainly on objective aspects of walking environments such as walking distance and safety (e.g., pedestrian causality numbers) or perceived evaluations of the built environment characteristics by audits.

Unlike these previous approaches to evaluating micro indicators, our research adds extra evaluation indicators of the characteristics of historical blocks, and introduces image segmentation using deep learning to quantitatively evaluate specific streetscape elements. We selected the most relevant macro and micro indicators in order to conduct a comparative evaluation using street view images, so as to evaluate historical areas more comprehensively and accurately.

Although we have the same number level of professional auditors (10-20) in similar macro and micro applied evaluation articles after creating brief evaluation indicator for some specific object (Zeng, 2020; Rebecchi, 2019), the auditors are lower than the research articles mainly based on subjective investigation or indicators verification (Cerin, 2011; ITDP, 2020). And the number of indicators is also lower than that of articles specially building index evaluation system (Cerin, 2011; Hanibuchi, 2019; Sallis, 2015; Malecki, 2014). These two points can be further improved in the future since our focus is on the construction of comprehensive methods of applied articles for the specific study of historical cities in this chapter.

In terms of research results, we have consistent results compared with similar research articles on Japanese and Chinese cities. Nagata's research (2020) on Japan highlighted the impact of built environments on walkability in the micro environment, in addition to enhancing accessibility to destinations on the macro-scale, which is basically consistent with our results in Kyoto. Zeng's research (2020) on historical cities in China shows that the change of street view environment and the increase of shops brought by the renewal plan have improved the walkability. This result is also consistent with Xi'an's high walkability due to the vitality of the streets. In addition to these, our results also better reflected the impact of the traditional streetscape of historical blocks on the improvement of walkability.

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CHAPTER 4

Changes in pedestrian street environments due to the COVID-19 pandemic in Xi’an

4.1 Introduction

The initial cases of the novel corona virus (2019-nCoV) occurred in Wuhan, Hubei Province, China, in December 2019 and January 2020 (Grainger, 2021). In December 2019, a cluster of patients with pneumonia of unknown cause was linked to a seafood wholesale market in Wuhan, China (Li, 2020).

Just as the workers returned home during the Spring Festival, covid-19 spread rapidly in China. The first case of COVID-19 in Xi’an was on January 22, 2020. During the Spring Festival, China has adopted strict sealing and control measures (Nhc.gov, 2020, Yang, 2021).

While strict containment measures have reduced the spread of the virus in China, the activity and mobility of the people have been severely limited, resulting in a sharp reduction in walking.

Therefore, it seems worthwhile to explore the changes in the streetscape environment since the pandemic. Nguyen (2020) utilized the largest collection of Google Street View images used for public health research to characterize neighborhood environments and found built environment characteristics can help establish the community-level COVID-19 risk.

Because of China’s zero COVID-19 strategy, the impact of the pandemic has been particularly prominent on walkability. Prior to the outbreak of COVID-19, the streets of Xi’an’s historic centers were alive with bustling crowds of people and stores on both sides of the street. However, during the pandemic, due to the restrictions on individual mobility and the preference of people for staying at home, the walking environment has changed substantially (Liu, 2022, Cai, 2022, Cheshmehzangi, 2021).

The chapter mainly focuses on the impact of the COVID-19 pandemic on streetscape environment, specifically in a built environment consisting of street scenes elements. Based on the street view data before and after the pandemic, we quantitatively compare changes in specific street view components through image segmentation of deep learning as a case study in Xi’an, and put forward constructive suggestions for the creation of a pedestrian oriented city in the post-pandemic era of Xi’an.

4.2 Method

4.2.1 Street view selection and download

The main urban area as the research object of this chapter is the same area in Xi'an of chapter 3. It is the older part of the urban area within the city wall. The selected area of 1.5 × 2.5 square kilometers, which includes the Beiyuan Gate and Sanxue Street historical blocks, is shown in Fig. 4-1.

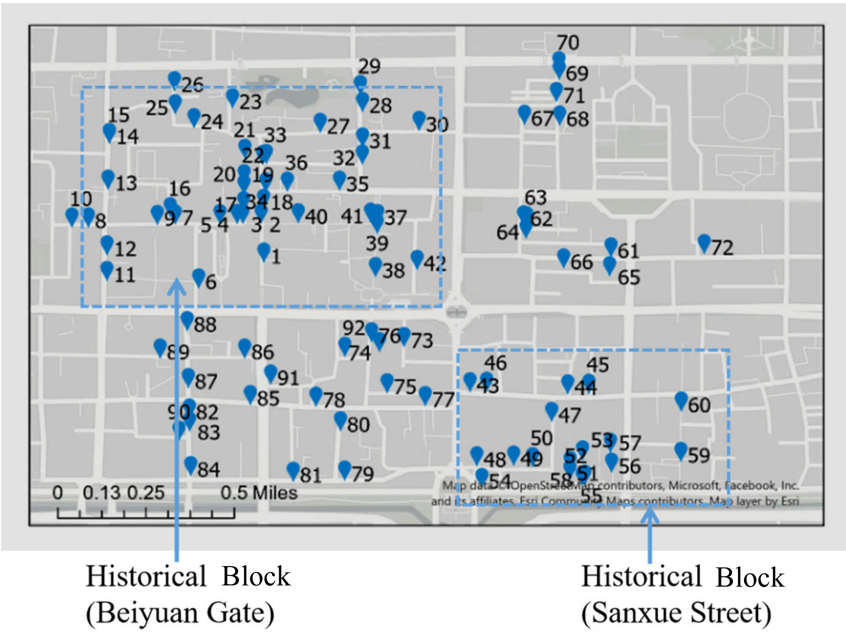

Fig. 4-1 Selecting points in Xi'an (92 points, including 65 historical blocks points)

The three-step selection procedure is the same as chapter 3, and is specifically described below:

1. Use street intersections as the selection points: All the intersections of the research area according to longitude and latitude were confirmed in ArcGIS, with some streets having several intersections. In our street view dataset, each intersection captured street view images from four directions (0, 90, 180, and 270 degrees).
2. Select the same two to three street views with the same angle for each street before and after the pandemic (The outbreak in Xi'an began in January 2020. The two selected periods are 2019, before the outbreak, and 2022, after).
3. Obtain again the street view image using API (Application Programming Interface) data from Baidu (Photo taken in Feb. 2019) and field survey by co-researchers (Photo taken in March 2022). The same street views of the two periods (before and after the pandemic) were selected for preparation. In total, the same 92 street views were used for each of the two periods in the historical blocks and the modern areas of the main urban area, and finally at each selected point, there are two street view images with the same angle of view and size for comparison (Fig. 2). It should be noted that our study is based on the examination of those photos which were taken in one season of each period (before and after the

pandemic). Both are in the winter and early spring time when the pedestrian flow on the studied streets is relatively less compared to that in the summer and autumn seasons. To overcome this limitation, longitudinal studies at different time periods should be considered for future investigation.

4.2.2 Street view segments recognition

To detect the component elements of each intersection's streetscape, we also used DeepLab v3+ model for semantic image segmentation, specific steps and methods for using the models are the same as chapter 3.

Finally, by identifying the pixels in each street view element classified into one of the 19 segments, the percentages of segments (hereafter, PSG) for each street view image can be calculated. And the average value of the overall extraction percentage for every image also reached 91.6% and 90.9 in 2019 and 2022, for a single image with large deviations, we also corrected it.

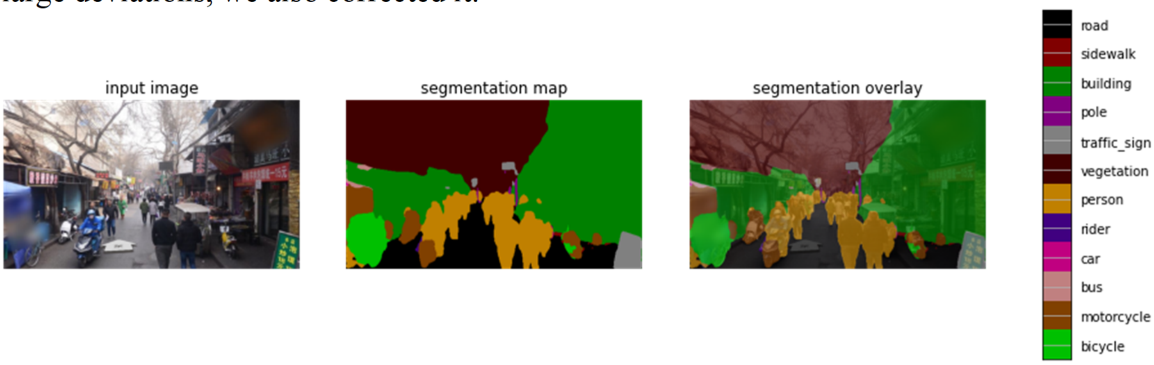

Fig. 4-2 Sample of segmentation map before pandemic in 2019 (No. 38)

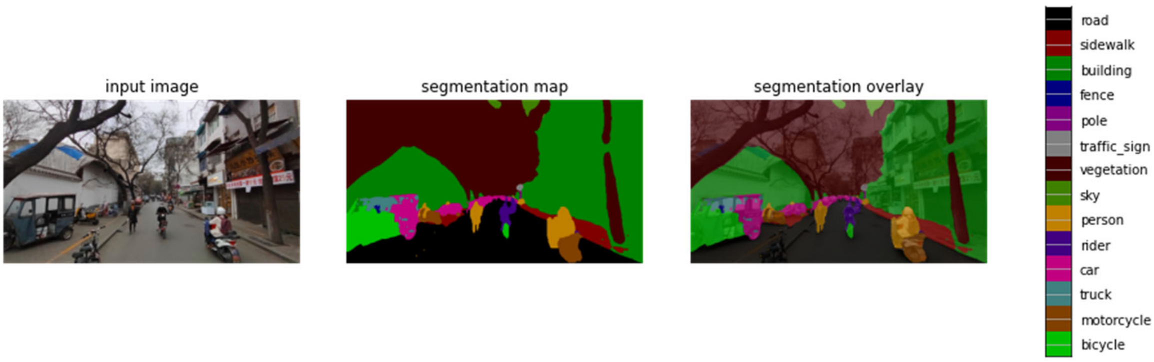

Fig. 4-3 Sample of segmentation map after pandemic in 2022 (No. 38)

Based on this, we completed the image segmentation of all the street scenes with the same virtual angle at 92 selected points in Xi'an before and after the COVID-19 pandemic. An example of the street view pictures before and after the COVID-19 outbreak is shown in Fig. 4-2 and 4-3 for Xi'an.

4.3 Results and discussion

4.3.1 Overall evaluation of street view segments recognition in Xi'an before and after COVID-19

As can be seen in Table 4-1, which shows the average PSG of all the selected points in Xi'an before and after COVID-19, fundamental composition rate of the primary the urban structure has not changed much over the past three years. The top three segments composing the street scenes in Xi'an in 2019 are "building," "road," and "vegetation." The segment of "building" has the largest proportion, accounting for 40.00% of the studied street views. The second largest is "vegetation," at 22.08%, followed by "road," at 12.68%. In 2022, "building" still appeared to be the largest proportion (40.56%). The next largest is "vegetation" (18.34%), followed by "road" (16.47%). The proportion of "building" in 2022 is similar to that in 2019.

Table 4-1 Average value of PSG of each class for all points in Xi'an before and after COVID-19

Group	Class (Segment)	Xi'an 2019 before pandemic (%)	Xi'an 2022 after pandemic (%)
Ground	road	12.679	16.467
	sidewalk	3.379	4.837
Building	building	39.998	40.563
	wall	2.370	0.863
Infrastructure	fence/stall	1.637	2.764
	pole	0.623	0.674
	traffic light	0.220	0.160
	sign	0.637	0.432
Nature	vegetation	22.081	18.346
Sky	sky	2.529	2.792
Human	person	4.333	1.867
	rider	0.671	0.622
Vehicle	car	6.629	3.569
	motorcycle	1.157	1.504
	bicycle	0.498	0.440

The proportion of the presence of a "person" in Xi'an is 1.87% after the pandemic, much lower than the corresponding 4.3% in 2019. Considering the reduction in the pedestrian proportion from 2019 to 2022, the proportion of Xi'an's "road" and "sidewalk" does not change much, and the street layout remains dominated by street trees on both sides of the street, which still accounts for a large proportion. As the road network has not changed, the proportion of "road" and "building" has not changed noticeably.

Through street view images of Xi'an, because the historical blocks are a tourist destination, there were many snack bars and signboards on both sides of the street, attracting large numbers of tourists before pandemic. Obstacles such as mobile stalls and fence are increasing in the historical blocks.

However, due to the impact of COVID-19, the number of tourists has fallen markedly, and some shops have been temporarily closed, resulting in a reduction of stores signs and a decrease in the continuity of shops, especially in the historical blocks (Fig. 4-4 and 4-5).

The roads in the historical blocks are relatively narrow, and most of the merged roads in Xi'an are pedestrianized. Because many locals and tourists come into the historic center, the main travel mode is walking.

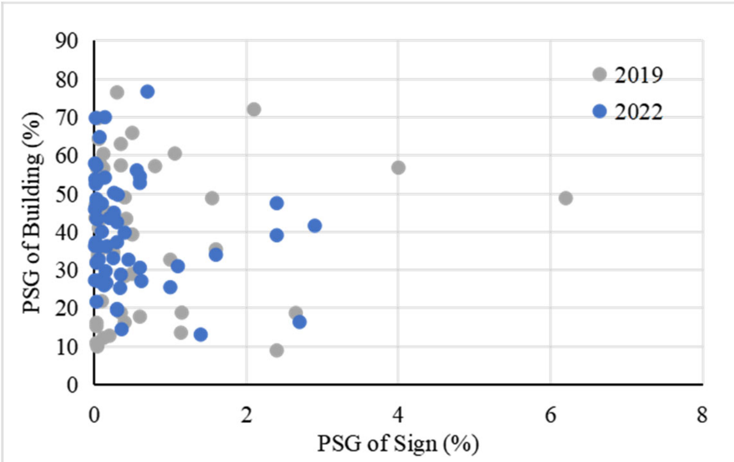

Fig. 4-4 PSG of building-to-sign ratio for selected points before and after the pandemic in Xi'an

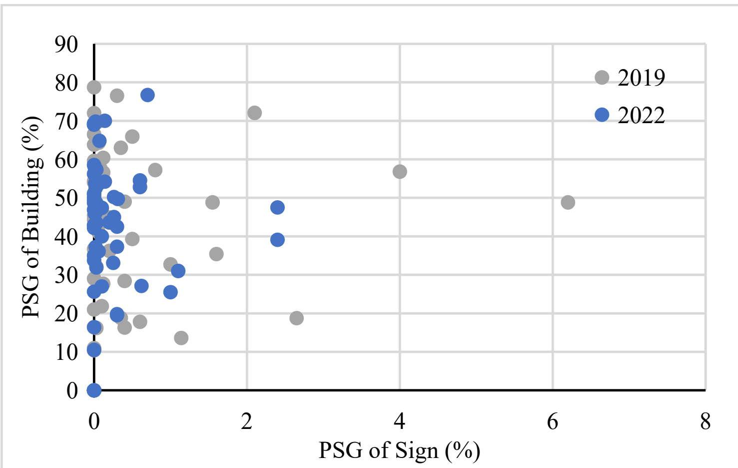

Fig. 4-5 PSG of building-to-sign ratio in the historical blocks in Xi'an

There are also large numbers of motorcycles used both for sightseeing and goods transport. Ordinary cars are inconvenient here and are generally restricted from entering the historic center, but a large number of cars and electric vehicles in Xi'an that hinder traffic, affect people's walking. Notably, after the pandemic, although there are fewer people and car, the proportion of motorcycles has not decreased, and local residents still use the more convenient motorcycles rather than bicycles in their daily life (Fig. 4-6 and 4-7). In Xi'an, there are only a few zebra crossings in the historical blocks, and the proportion of electric poles and light boards is small due to the blockage caused by trees.

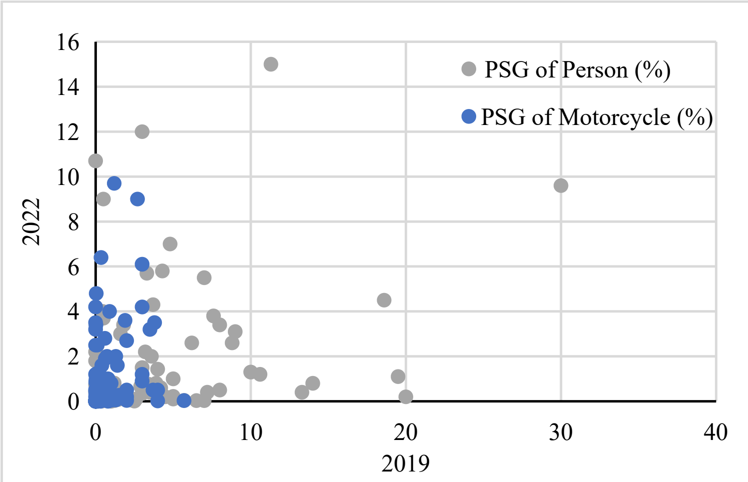

Fig. 4-6 PSG of person and motorcycle in Xi'an

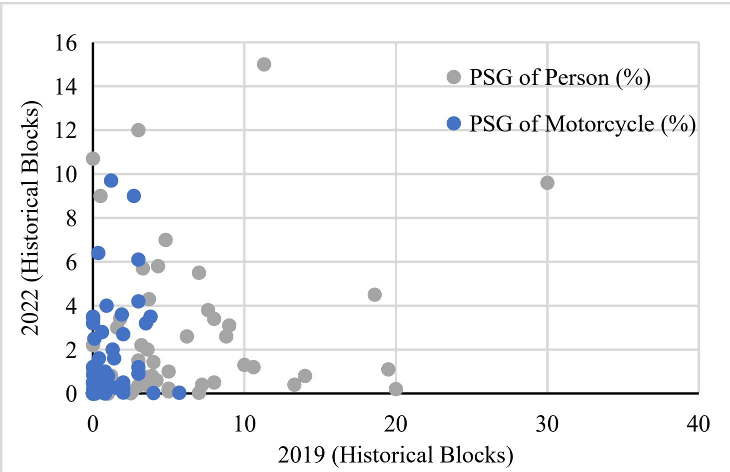

Fig. 4-7 PSG of person and motorcycle in historical blocks in Xi'an

4.4 Conclusion

This chapter examine the change the components of street views in the main urban areas of Xi'an before and after the COVID-19 pandemic, the composing elements were quantitatively described through image segmentation using street views of selected points, and the spatial characteristics of the pro-pandemic and post-pandemic periods were compared.

In Xi'an, the basic street network or structure has remained essentially the same, and the top three segment proportions of "building" "road" and "vegetation" did not change substantially between the two periods, while the proportion of the presence of "person" fell dramatically, from 4.3% (2019) to 1.87% (2022).

The decline of street vitality, particularly in terms of street aesthetic and commercial values, seems to have a negative impact on the walkability of the studied area. Parking and traffic safety problems caused by the increased use of motorcycles also have an obvious negative effect. To create a walkable street, obstacles such as parked motorcycles should be removed, while improved safety measures to pedestrians and the role of characteristic and commercial atmospheric aspects in increasing the vitality of streets should be reconsidered in historical city.

As a factor having real influence on streetscape of walkability, the pandemic situation needs to be taken into account when developing evaluation for future research.

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CHAPTER 5
Conclusions

5.1 Summary findings and their implication

As part of a larger effort to make a pedestrian-friendly city, this paper aims to identify improvement areas in the historic built environment that will encourage and facilitate walking activities.

To this end, we comprehensively compare the specific effects of macro street structure factors and micro street scenes factors, identifies the factors that impact on increasing the walkability, specifically examined the walkability of ancient capital cities with combining macro and micro factors, using Xi'an Kyoto as an example.

Chapter 1

In Chapter 1, demonstrates research background of the study, significance and the objectives that establish the main aim of this research. In addition, it elaborates the organizational structure of the research frameworks and methods.

Chapter 2

In this Chapter, we analyzed of urban spatial structure changes during the process of modernization in historical cities, focusing on historical capital cities, Xi'an and Kyoto. And then we investigated the evolution of the morphological characteristics of the typical walking space from the street structures and network systems perspective, and examined the shift in the topological relationship between historic block space and urban whole space.

The results are shown as follows:

1)With the expansion of the urban area, the topological centers changed correspondingly. It was found that the topological center in the main urban area of Kyoto clearly expanded outward from 1902 to 2020 in both the horizontal and vertical directions simultaneously. In Xi'an, the area expanded from one topological center centered on the bell tower in 1949 to two topological centers in 2019. Int-Rn (global) increased markedly for the two cities, and it suggested that long-distance accessibility increased during the period of modernization. The implication is that the modernization of the two cities was heading toward motorization.

2) The global and local integration correlation of the two major urban areas is reinforced by the characteristic curve and index analysis, with the two exhibiting strong similarity. If the intelligibility (R^2) value of local space is low, the indication is that the local centrality of the regional urban space cannot be integrated with the global space and is thus relatively isolated. In this study, the intelligibility (R^2) value increases in both Xi'an and Kyoto, meaning that the solidarity of the respective regions has

increased during the modernization process.

Chapter 3

As part of our exploration of pedestrian-friendly city planning, we first reviewed existing research to find suitable indicators for evaluating the walkability of historical Asian cities. Our ultimate aim was to identify specific improvements that would promote walking activities in historical building environments. We then used a checklist based on the selected indicators to evaluate walkability in Xi'an and Kyoto and identified key factors that improve or hinder the walking environment in the historic central districts of the two cities.

1) Comparing the walkability evaluation scores (WES) for the two cities, we found that the average overall perceived and objective scores for walkability in Xi'an were slightly higher than in Kyoto. While Kyoto had a higher perceived evaluation in cleanliness, maintenance level and design of the built environment, Xi'an was clearly superior to Kyoto in terms of attractive and lively built environment. Xi'an scored higher in the objective evaluation, with sidewalk, vegetation, and people flow as obvious advantages. The only exception was the large number of vehicles on Xi'an's streets, which hinders pedestrian traffic flow and adversely affects walking.

2) Both historical cities are based on a similar urban structure, many of the streets in Kyoto are more modernized than those in Xi'an. The wider streets of Kyoto tend to produce high Int-R3 in the city's modern areas due to their recent, car-oriented development. Walkability in Xi'an was found to be better than in Kyoto based on higher scores for specific walking environment factors as assessed by the micro indicators of perceived walkability.

3) To produce an appropriate tool for assessing walkability in such historical cities, we found that combining macro-scale indicators that measure accessibility in the street structure with micro-scale indicators for the built environment pertaining to daily human activities and pedestrian movement at the street-level is highly important. These two types of indicators were found to be independent of one another, with no obvious correlation. It suggests that the introduction of a micro indicator for walkability assessment (WES) has a significant meaning. Thus, it is evident that considering the micro and macro indicators together is necessary.

4) In cases where both the macro and micro indicator scores are comparatively high, places with good walkability in the two historical cities have several factors in common, including good accessibility, spacious sidewalks and more vegetation. It was found that there are two types of walkable areas: one that has numerous attractive shops and traditional cultural street landscapes, while the other is obstacle-free and has a clean and tidy built environment.

5) In cases where the macro indicators are high, but the micro indicators are low, it was found that the common factors include very good accessibility in the modern area and a well-maintained built environment. On the negative side, such places lack spacious sidewalks and have many obstacles, less vegetation, and a less-than-lively built environment. In cases where the macro indicators are low, but the micro indicators are high, it was found that such places have traditional cultural street landscapes and a

clean and tidy built environment in common. They also share the same problems, including poor accessibility in a fragmented street network and many obstacles, no spacious sidewalks, and less vegetation.

Chapter 4

This chapter examine the change the components of street views in the main urban areas of Xi'an before and after the COVID-19 pandemic, the specific composing elements were quantitatively described through image segmentation using street views of selected points, and the spatial characteristics of the pro-pandemic and post-pandemic periods were compared.

In Xi'an, the fundamental street network or structure has essentially not changed over the past two periods, and the top three segment proportions of "building" "road" and “vegetation" have not changed significantly, while the presence of "person" has decreased dramatically, from 4.3% (2019) to 1.87%. (2022).

It was determined that declining street vitality, particularly in terms of street aesthetic and commercial values, had a detrimental effect on the study area's walkability. There is little doubt that the rising usage of motorcycles has a detrimental impact on parking and traffic safety. Obstacles like parked motorcycles and fence, stand should be eliminated in order to make a street walkable. Also, pedestrian safety measures should be enhanced, and the contribution of historical characteristics and commercial elements to a street's vitality should be given another thought.

While creating evaluation indicators for future study, it is important to include the pandemic situation as a component that has a genuine impact on the streetscape and walkability.

5.2 Proposal and future research

Several recommendations emerge from our study results. For example, Xi'an needs to consider the potential negative impact on walkability in parallel with pursuing increased modernization, as has been done in Kyoto. To improve walking accessibility, Xi’an's built environment and the infrastructure of its streets need to be improved by reducing obstacles such as parked motorcycles to provide more space for pedestrians. The city also needs to maintain its historical street view and the current amount of vegetation. In Kyoto, while still maintaining its good walking environment, the focus should also be on improving the vitality of its streets, a critical part of creating a pedestrian-friendly city. For any historical city, it is important to maintain the infrastructure while preserving the unique characteristics of its historical street view and promoting the vitality of its streets.

To the specific stakeholders especially for Xi'an, in the process of its rapid development, the reconstruction of historical blocks will face more conflicting problems of development and protection. For the municipal planning department, while transforming the dilapidated historical blocks and optimizing the business model, it is more important to dredge the internal broken streets according to the historical context and space, maintain the outdated infrastructure of the historical blocks, and improve people's living and walking environment. Also for Kyoto, since it is in the era of rapid modern development of car centered life, such urban charm has been damaged, and many developments have occurred along wider streets, and Kyoto's walkable areas are now fragmented. The Kyoto government should take measures to improve the charm and vitality of the streets while encouraging the walking mode suitable for people in Kyoto.

As two cities at different stages of development, Xi'an and Kyoto can provide some valuable suggestions for the walkability of other similar historical cities, which can be used as a breakthrough point for in-depth study of the rule of walkability development and change in combination with more other historical cities in the future. Finally, generally speaking to increase general walkability for other historical cities, we believe that negative elements for walkability firstly should be removed. This can be achieved by reducing obstacles or parked motors and providing better safety measures for streets. In contrast, the commercial and historical features elements increasing the vitality of streets should be more taken into account under the current circumstance.

Regarding the limitations and future plan, the scope of this study is specifically limited to the historical Asian cities of Xi'an and Kyoto. Moreover, the study relies on images of selected street views taken at particular times and on particular days in 2019, prior to COVID-19 pandemic. Future research is being considered to overcome these limitations. A longitudinal study using the same methodology for post-pandemic periods is contemplated, one that includes more than a single season in order to account for seasonal differences in traffic flow, etc. Additionally, a comparison study that includes several regions in different countries could produce more generalizable results.

In the macro structural analysis of space syntax, although both Kyoto and Xi'an are historical cities, the main urban area of Xi'an has obvious boundaries by city wall, while Kyoto does not have. In future research, more historical urban area should be compared to find out the specific impact. In addition, the selection of the core area should also be noted, which should largely affect the connectivity of the axis.

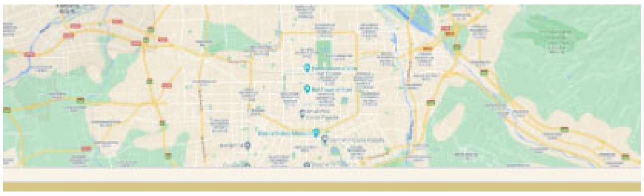
In terms of specific analysis and evaluation, for the collection of street views, it is easy to randomly appear some influential elements in the street view pictures, so the number of samples should be as large as possible to reach the average value in a street situation.

When using the ready-made walkability evaluation indicators, the indicators should also be better adjusted according to the specific local conditions to better reflect the specific characteristics of the local walkability. For the selection of auditors, it should be acknowledged that the selection of the auditor team was rather based on are a convenience sampling since the availability of the auditors was limited to our colleagues when the study was conducted. After finishing model, it is also a part of the model establishment to constantly correct the walkability model as time changes.

Appendix

1. Questionnaire using Google Forms (Chapter3)
2. Depth map (Chapter2)

1. Questionnaire using Google Forms (Chapter3)



Walkability(Xi'an)

First take a look at all 108 pictures, and have an overall impression. Then complete the evaluation of six perceived indicators of all pictures.
Please select pictures as many as you like, thanks a lot.

What do you think about following pictures ?
Please check if you agree with the following statement.

1. Not well-maintained built environment built environment *(Negative)*

- Please select the street views that have presence of decrepit infrastructure, badly maintained street furniture, and abandoned building.

Please select the places where you think the streets are dirty and scattered (litter, garbage, broken glass, etc.)

3. Built environment with a lot of obstacles *(Negative)*

In which street-views do you think there are many obstacle (bicycles, two-wheeled electric vehicles, uneven pavement, signboard, etc.) on the road that affect walking.

4. Well-designed build environment (beautiful/ aesthetic) *(Positive)*

Please select the places where you think the built environment are well-designed (for example, harmonized architectural style and design).

5. Attractive and lively built environment (presence of commercial and attractive shops) *(Positive)*

Please select the pictures in which you think there are attractive and lively built environment (mainly presence of attractive and lively shops)

6. Traditional streetscapes/preservation of historic buildings *(Positive)*

Please select the pictures in which you think there are traditional streetscapes and historical buildings.

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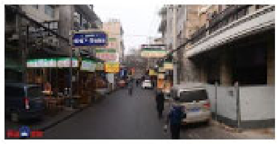

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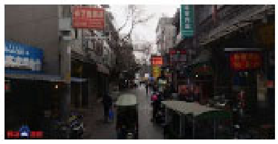

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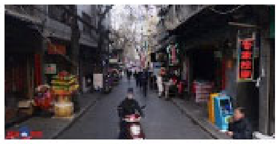

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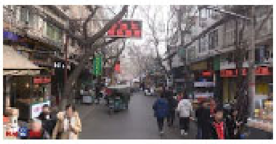

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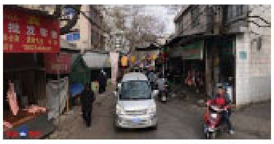

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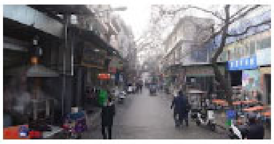

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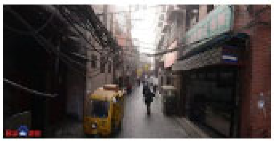

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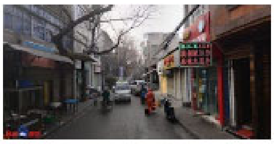

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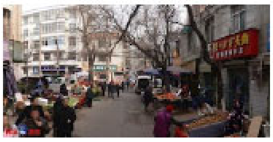

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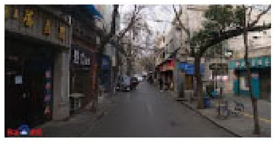

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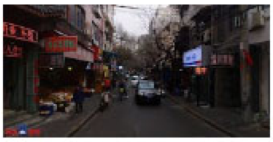

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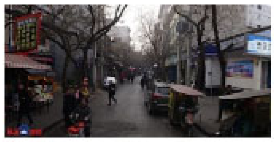

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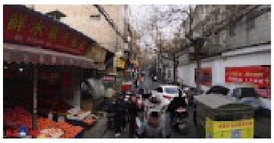

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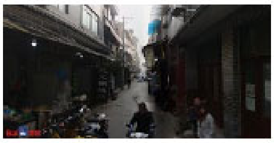

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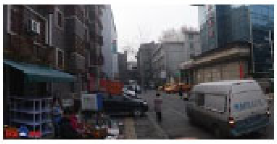

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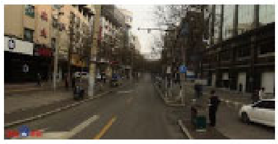

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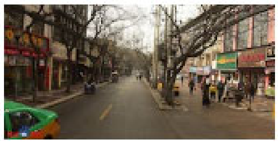

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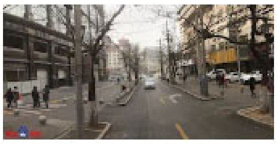

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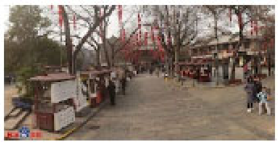

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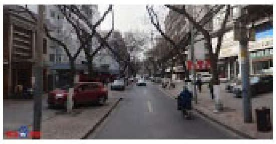

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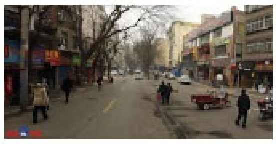
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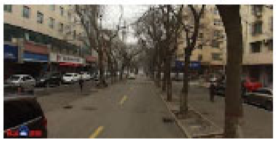
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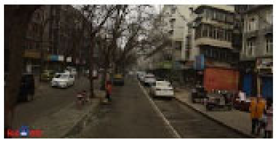
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选项 90

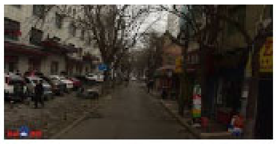

选项 101


选项 102


选项 91


选项 92


选项 103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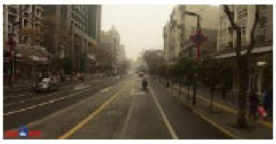
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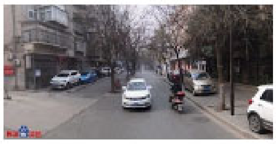
选项 94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选项 95


选项 96


选项 107


选项 108

Walkability(Kyoto)

First take a look at all 112 pictures, and have an overall impression. Then complete the evaluation of six perceived indicators of all pictures.
Please select pictures as many as you like, thanks a lot.

What do you think about following pictures ?
Please check if you agree with the following statement.

1. Not well-maintained built environment built environment *(Negative)*

- Please select the street views that have presence of decrepit infrastructure, badly maintained street furniture, and abandoned building.

2. Dirty and scattered built environment *(Negative)*

Please select the places where you think the streets are dirty and scattered (litter, garbage, broken glass, etc.)

3. Built environment with a lot of obstacles *(Negative)*

In which street-views do you think there are many obstacle (bicycles, two-wheeled electric vehicles, uneven pavement, signboard, etc.) on the road that affect walking.

4. Well-designed build environment (beautiful/ aesthetic) *(Positive)*

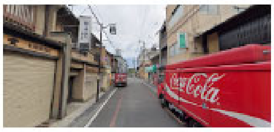
Please select the places where you think the built environment are well-designed (for example, harmonized architectural style and design).

5. Attractive and lively built environment (presence of commercial and attractive shops) *(Positive)*

Please select the pictures in which you think there are attractive and lively built environment (mainly presence of attractive and lively shops)

6. Traditional streetscapes/preservation of historic buildings *(Positive)*

Please select the pictures in which you think there are traditional streetscapes and historical buildings.



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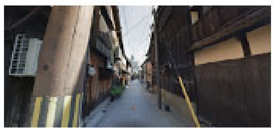

☐ 12

https://docs.google.com/forms/d/e/1FAIpQLSdCV6x_5QiQJqSdmEjGbzwww6NIgd722OeOQ5y46KRWO4hEDw/viewform

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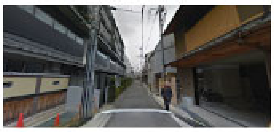

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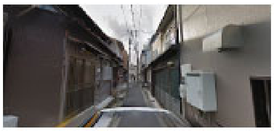

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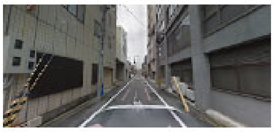

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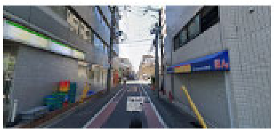

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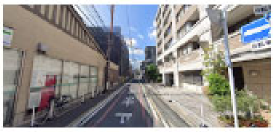

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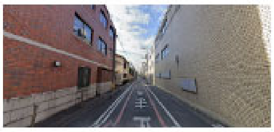

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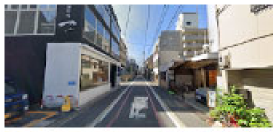

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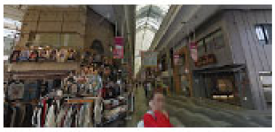

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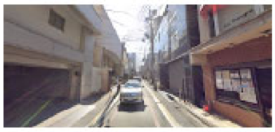

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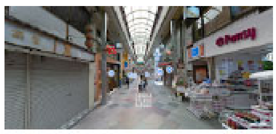

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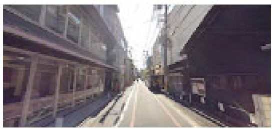

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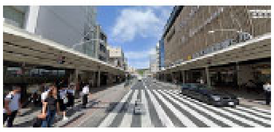

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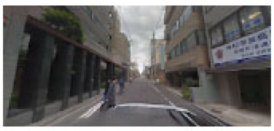

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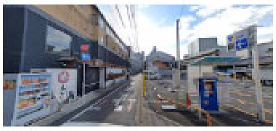

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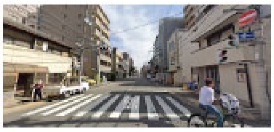

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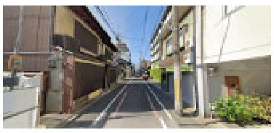

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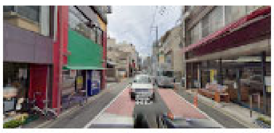

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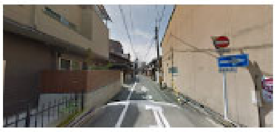

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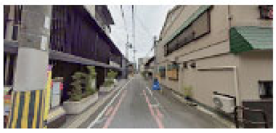

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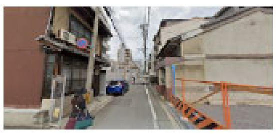

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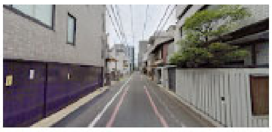
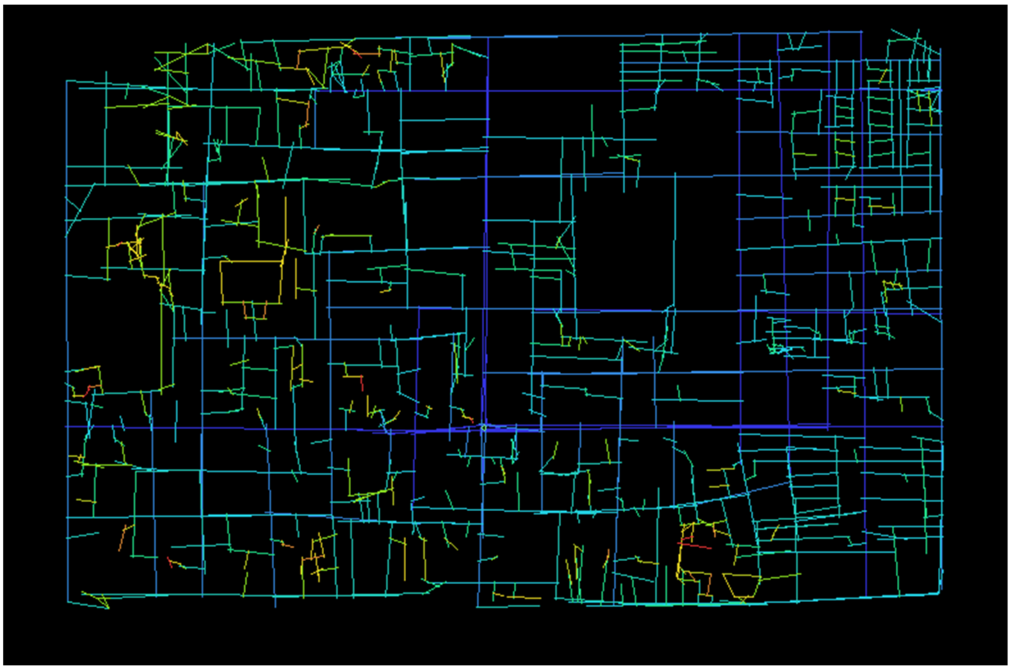


112

2. Depth map (Chapter2)

Xi'an 1949

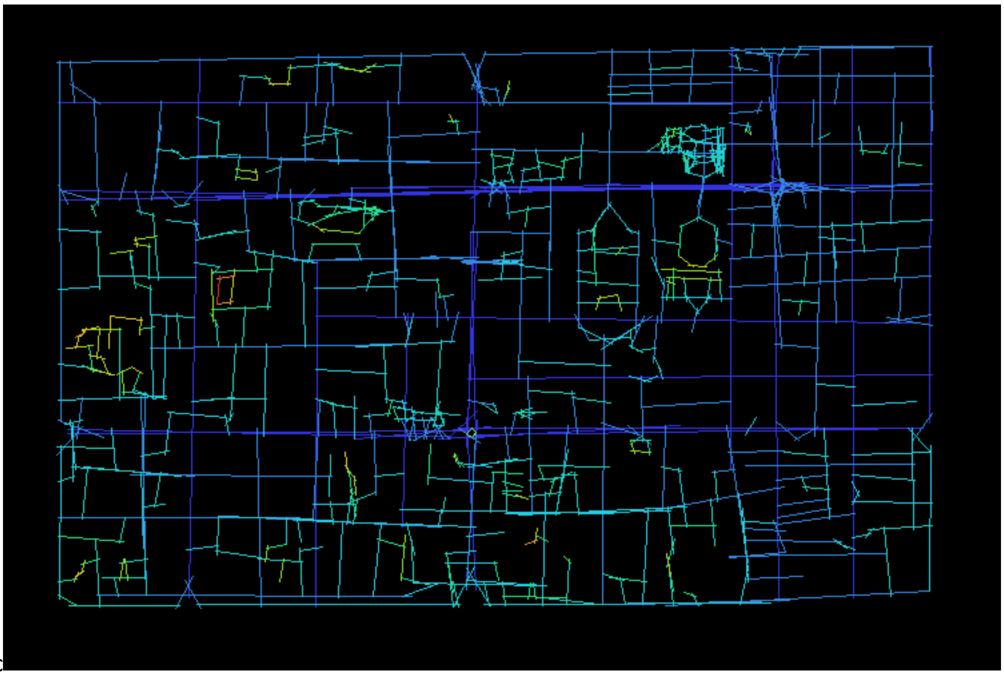


Depth value

6309

2594

Xi'an 2019



Depth value

6543

2241

Kyoto 1902

Kyoto 2020