A new perspective on urban form with the integration of Space Syntax and MCDA

– An exploratory analysis of the city of Xi'an, China

by

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Author's declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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Abstract

The research on urban form and its related socio-economic activities have been undertaken for long, while the evolution of research approaches and tools are limited by the conventional medium such as maps to interpret the built environment. Emerging new urban data has equipped urban morphologists with innovative datasets for urban form studies. This thesis aims to explore and interpret the urban form from a new perspective, which integrates spatial patterns generated from Space Syntax analysis with new urban data in GIS using Multi-Criteria Decision Analysis (MCDA). Xi'an, as one of the most renowned historic cities in China, is selected as the case since the city has undergone an unprecedented transformation of urban form in the last decades. In this research, the space syntax model of Xi'an is built primarily based on the OpenStreetMap (OSM) with further refinement by the Baidu Map. The Point of Interests (POI) data acquired from the Baidu Map API serves as the main datasets for the criterion of MCDA. The social data of human movement flow is gathered by the gate observation in five representative districts in Xi'an. The correlation analysis with observation data is employed to compare the result of the original Space Syntax analysis and MCDA to consolidate the understanding of urban form. This research provides urban researchers with new insights into urban form in terms of the application of new urban data, the invention of a new research method, and the new perception of the City of Xi'an. The findings suggest that the new perspective can facilitate the quantifying process and enhance the comprehensive understanding of urban form. Based on the research, recommendations for further studies and urban planning of Xi'an are discussed.

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Chapter 1: Introduction

Facing the trend of urbanization, the majority of Chinese cities have experienced significant urban form transformations in the last decades. As a concrete medium to read the city and unravel the inner mechanism, the physical form of the built area has been the foci of urban researchers for long. This research aims to interpret the urban form from a new perspective based on a case study in the city of Xi'an China. In this chapter, the background of the research is presented, followed by the proposed research questions and a discussion of the outline of the thesis.

1.1 Background

1.1.1 The urbanization of China

The last decades witnessed the unprecedented urbanization and urban form transformation in Chinese cities. In the context of planning for growth (Wu, 2015), both the urbanized population and urbanized land area have expanded dramatically. With a total population of 1.39 billion, China's urbanization rate has increased from 38% to 56% from 2001 to 2017. Similarly, the number of cities experienced a dramatic surge from 193 in 1978 to 676 in 2009 (National Bureau of Statistic of China, 2017). Currently, there are more than 700 million people inhabit China's urban areas, and around 30 million migrants are entering the urban environment every year. The same explosive growth can be seen in the built-up land area over the past decade China with the growth rate of 78.5% compared to 46% urban population growth (Bai, Shi, & Liu, 2014). These changes have severely impacted Chinese cities' physical fabric as well as social-spatial transformation.

Before the implementation of the Reform and Opening Up Policy in 1978, China's urban development is anchored with the ideology of social egalitarianism and the principles directing the process aimed at creating a standardized urban form (Wu & Gaubatz, 2013, pp. 152–153). The most symbolic element of the urban landscape then is the work unit and the residential area associated with it, the work unit compound. The work unit and related construction dominated in the city under Mao (1949-1976) and contributed significantly to Chinese society in economic, political and social dimensions. The spatial form of the work unit has created a compact and self-sufficient community for residents, where a variety of amenities and social services are equipped (Lu, 2006, p. 48). The conventional urban form was gradually encroached by the unprecedented force of property development and urban expansion driven by economic development due to the marketization and globalization after 1978.

While China as a whole has undergone the rapid urbanization process, the large scale urban development in China is unbalanced (Cao, Lv, Zheng, & Wang, 2014). In terms of the regional dimension, the central and western regions witnessed rapid urbanization under the command economy during the pre-reform period (1949-1978), while the eastern region has demonstrated significant urban growth since 1978 (Anwaer, Zhang, & Cao, 2013). Nowadays, eastern coastal cities such as Shanghai, Guangzhou, Shenzhen, and Hangzhou have garnered worldwide popularity (Qian, 2015; Wu, 2000; Wu & Zhang, 2007) while leaving western cities underexplored. As the largest city in northwest China, Xi'an was not the foci of the national development strategy until early 2000 when China began a profound long-term policy – the China Western Development. The population of the sub-provincial city Xi'an has increased from 7.41 million (2000) to 9.05 million (2017), and the urbanization rate has also risen from 60% to 72% during the same period (Shanxi Provincial Bureau of Statistics, 2017). Under the interplay of institutional, economic and social forces, the urban form of Xi'an has undergone tremendous transformations: from "stable increase" to "fluctuating increase", from the structure of multigroups to concentric circle, from south-oriented development to north-south oriented development, and from land infill to building on peripheral enclaves (Liu, Ren, Ma, & Tian, 2016).

1.1.2 Researches on urban form

The urban form long been an intriguing proposition for urban researchers. Understanding city or human settlement from the physical configuration or formation perspective is the motive behind many types of research. With the inherent complexity of cities, scholars from diverse fields, such as architecture, planning, geography, and economics, are devoted to undertaking interdisciplinary methods to analyze the built environment around us. Nevertheless, it is hard to give a precise and comprehensive definition regarding the extensive range it relates. While the term is widely used, "urban form" in the field of urban morphology is typically interpreted as "the main physical elements that structure and shape the city—urban tissues, streets (and squares), urban plots, buildings, to name the most important (Oliveira, 2016, p. 2)." However, urban morphologists' definition may not be applicable in other fields and nor are their research approaches (Kropf, 2009).

It is noted that studies of urban form rely heavily on cartographic representations such as maps and plans, which are effect and idealized model for the existing or precedent city. Previous methods for analyzing and interpreting the urban form were mainly qualitative and involved the subjective judgment by researchers, which makes it hard to integrate different research findings as well as providing a detailed or precise explanation to the phenomenon. In recent years, the growth of geographic information science and technologies have promoted the analysis of urban form and urban modelling (Batty, 2013b) for exploring as well as explaining the urban form from both qualitative and quantitative perspectives. With the advancement of spatial analysis technology, emerging alternatives for assessing, classifying, and representing the spatial and socio-economic characters of the urban form have been widely adopted by “mathematical modellers” (Conzen, 2010, p. 56), who come from multidisciplinary fields including architecture, planning, geography, and engineering. Compared to the conventional methodology, which associates the diagram with the real built environment, this type of research focuses on an abstraction of the city and the algorithm behind the urban modelling.

Regardless of the technology and methods, the research that been implemented hitherto could be regarded as attempts to model the city. The last couple of decades have seen models become increasingly fine-grained (Stanilov, 2010). A strand of literature focus on simulating and summarizing the inner spatial mechanism of the city from the macro-economic and social physics perspective, proposing models including the Concentric Zone Model by Ernest Burgess (1935), Sector Model by Homer Hoyt (Hoyt, 1939), Multiple Nuclei Model by Chauncy Harris and Edward Ullman (1945), and Edge Cities by Joel Garreau (1992). Meanwhile, the development of urban models, especially those associated with spatial analytical approaches, has expanded the dimension regarding interpreting urban form. The most notable recent achievements in the realm of the urban model are found in cellular automata (CA), and agent-based modelling (ABM) approaches (Batty, 2005; Parker, Manson, Janssen, Hoffmann, & Deadman, 2003). Both approaches thrive on understanding the process of urban growth and urban form transformation by either simulating land-use transitions or via simplified designed rules. Also, another branch of urban modelling - the school of space syntax (see work by Hillier & Hanson, 1984) - concentrates on the pure physical configuration of the built form, paying special attention to the network structure by transforming the road network to the axial map and segment map for further exploration. The miscellaneous approaches, on the one hand, facilitate the exploration and explanation of the urban form simultaneously; on the other hand, impose challenges for synthesizing the findings from different fields.

As such, the challenges facing urban researchers nowadays is not how to distinguish these methods, but how to combine and coordinate them. Kropf (2009) proposed four broad types of urban form research, including spatial relations of physical features, the interrelation between humans and physical features, flows, and land-use changes. There are also several sub-categories under each theme, which are detailed classifications based on Kropf's comparative analysis on four identified analytical approaches, including "spatial analytical, configurational, process typological, hitorico-geographical." Amid these research approaches, this thesis intends to make connections between two of them: the spatial analytical and configurational approaches. To be specific, this research integrates the GIS-based Multi-Criteria Decision Analysis (MCDA) with the Space Syntax analysis to examine the existing urban form of the city of Xi'an.

1.1.3 New urban data

In the era of booming information technologies, the individuals in the city have been closely connected by the digital network whereby generating various first-hand datasets that could potentially facilitate the urban studies. The urban data, by its definition, is the data representing the static and dynamic aspects of the city, and always associated with both spatial and temporal dimensions. The advancement of geographic information science has made it possible to georeference everything in the city, thereby fostering the new science of cities (Batty, 2013b). The emerging research topic of big data has rooted in this context and drawn attention from various subjects, including planning, geography, data science, mathematics and computation, and computer science. The big data, by its nature, are of large volume, various diversity, and high velocity. However, the concept of big data is not new but a continuously updated one considering the fact that the development in data processing always lags behind the increase of data size (Batty, 2013a). In addition, thanks to the infrastructure upgrade, the automated sensors dispersed in the city contribute to the advancement of citizen-generated data.

According to Zhou and Long (2016), the new urban data is differentiated from the traditional urban data with a larger volume, higher resolution, more dynamic, and human-centred. It is noted that traditional datasets are mainly the effort of governments including census data, remote sensing images, cadastral maps, and planning documents, while the new urban data comes in miscellaneous digitalized forms and origins such as individuals, communities, business corporations, public institutions and governments. Recently, the open data movement, as well as crowdsourcing data initiatives, have significantly contributed to the data environment to make the local data more accessible for others to manipulate. In this research, two types of new urban data are introduced as the rudimentary elements representing the generic urban form of the study area, including the OpenStreetMap (OSM) and Point of Interest (POI). The POI data in this research are structured data acquired from the Baidu Map API that record the name, land-use, coordinates, address and type of the entities. The street networks data acquired from the OSM is the primary determinants in modelling the configurational dimension of the city of Xi'an, and the POIs play the role of "functional attractors" that have the magnetic forces attracting the human activities. Both the datasets are closely relevant to our research process, and the easy accessibility of these datasets makes it applicable for this research and further research to progress on this research topic. Meanwhile, with limited access to official urban datasets, the urban researchers or local citizens could also utilize new urban datasets like these two for underlying urban studies.

1.1.4 Space Syntax and MCDA

The main proposition of space syntax is to unravel the relationship between space and society by analyzing the configuration of the built environment and human movement (Hillier & Hanson, 1984). By investigating the accessibility of the street network in the city, Space Syntax could facilitate the interpretation of the existing physical urban structure and the prediction of the human movement pattern. The research emerged in the University College London (UCL) in the 1970s and progressed with a serial of publications adding to the soundness of theory and the practicability of the methodology (Hillier & Hanson, 1984; Hanson, 2003; Hillier, 2007). The approach is widely applied in space analysis with both building and city scale, and the indicators like integration, choice, intelligibility, and intervisibility (Hillier et al., 1993; Hillier & Iida, 2005; Hillier, 2012) are the main reference for evaluating the space.

In the field of Space Syntax, the configuration of the space is the predominant criterion in understanding and predicting the human movement in the city. However, the human movement in the real city is a complexity that attributes to various factors. Generally speaking, GIS is "a decision support system involving the integration of spatially referenced data in a problem solving environment" (Cowen 1988, p. 1552), and the introduction of MCDA into GIS provides more advanced research approaches for both spatial analysis and decision support with the ability to consider, combine and balance both quantitative and qualitative criteria simultaneously (Greene, Devillers, Luther, & Eddy, 2011). Therefore, the implementation of GIS-MCDA can add multi-dimensional perspectives to the traditional Space Syntax analysis, fostering the understanding of the urban form.

1.2 Research questions

With the growing volume of open urban data that been made available to researchers, the methods of urban studies have evolved simultaneously. The idea to use Geographic Information Systems (GIS) to undertake the quantitative analysis of urban form has been proposed for long (Moudon, 1997), and integration of space syntax into GIS has also been explored (Gil, Varoudis, Karimi, & Penn, 2015; Jiang & Claramunt, 2002; Li et al., 2017; Omer & Kaplan, 2017). Building on the discussion above, this thesis aims to respond to the following research questions:

1) Firstly, how can emerging new urban data facilitate the interpretation of urban form?

2) Secondly, how can MCDA be integrated with Space Syntax analysis in the urban form research?

3) Thirdly, how can a linked MCDA-Space Syntax approach aid understanding of the existing urban form of Xi'an?

These three research questions are inspired by the recent work in urban morphology field (Oliveira, 2016) aimed at combining both qualitative and quantitative approaches in the era of burgeoning information and communication technology. The first question focuses on the importance and feasibility of utilizing new urban data in current urban form research, and introduce an underlying dataset for urban studies. The second question is designed to overcome obstacles pertains to research methods by combining a spatial analytical approach with the configurational approach. In response to the question, this research expands the traditional research domain of the space syntax as well as MCDA. Finally, the third question examines the application of the proposed research method in the city of Xi'an. Notwithstanding rapid urban development in contemporary times, the historic city of Xi'an retains some of the characteristics inherited from the old days. With the results generated from the analysis, the current characteristics of Xi'an's urban form will be better represented and interpreted. The three research questions serve as an outline of this thesis and pave the way for the smooth progress of following each chapter.

1.3 The outline of the thesis

This thesis progresses in the following manner. After the introduction chapter, the literature review chapter examines and synthesizes the existing studies on the proposition of urban form by delving into the theory of urban morphology from four analytical perspectives, namely the historico-geographical, typological, space syntax, and spatial analytical. The progress and trajectory of related research in China are also presented with the identification of current research gaps as well as future research opportunities.

Chapter Three introduces the research approach, and the analytical framework utilized in this thesis are first introduced, followed by a description of the case study, including the city of Xi'an and five selected districts. Subsequently, the datasets used in this thesis are presented regarding the procedures of collection, cleaning, management, and manipulation. The two primary analytical methods, space syntax analysis and multi-criteria decision analysis, are latter discussed and implemented to empirically investigate the urban form of the selected cases.

In Chapter Four, the major findings from the analysis are discussed in relation to the research questions. The urban form and spatial structure of the city of Xi'an and five selected districts are generalized and compared through both a qualitative and a quantitative lens. In addition to the findings, Chapter Five discusses the contribution of the thesis as well as the limitations and recommendations for future relevant studies.

Chapter 2: Literature Review

To systematically examine the research proposition of urban form and identify the existing research gaps in the field, this chapter discusses urban morphology, morphological approaches, empirical practices in China, and research opportunities. These aspects cover a broad range of theoretical frameworks as well as research methods that anchor the studies of built urban form. All of these discussions have a substantial influence on this research in either a direct or an indirect manner.

2.1 Urban Morphology

As the most influential field of knowledge focusing on urban form, urban morphology has emerged over a century to become an interdisciplinary and international subject (Whitehand, 2018). Cities are complex and diverse from inception. Urban morphologists aim to unveil the relationship between different elements in the city that are moulded by the interplay of social and economic forces, such as the buildings, streets, squares and monuments. The primary responsibility of the urban morphologists is to "analyze a city's evolution from its formative years to subsequent transformations, identifying and dissecting its various components" (Moudon, 1997, p. 3). There are three schools leading the development of urban morphological research in the late twentieth century, which are the British School (Whitehand, 2001), the Italian School (Cataldi, 2003), and the French School (Castex & Panerai, 1982).

The British School is represented by Conzen's innovative and comprehensive work with the town of Alnwich (Conzen, 1960). Conzen made a major contribution by establishing a research framework for investigating historical towns from a hierarchical perspective to understand the urban form: town plans, building arrangements, and land and building use (Conzen, 1960, p.3). With inherent ideology from German geography, Conzen coined significant terms representing the identical features of the research areas, such as the Fringe-belt (Conzen et al., 2012). The Conzen's legacy influenced and inspired subsequent researchers, leading the establishment of renowned British School or Conzenian School, which shed light on urban morphology studies internationally (Whitehand, 2001). However, the primary challenge for promoting Conzen's theory is the heterogeneity of the vernacular planning system of different countries as well as the distinctive morphogenesis process. Gu and Zhang (2014) identify that there are limited cartographical sources for urban morphological research in China, which impede the researches following the British School since they are highly reliant on the documented maps or plans.

While the British school originated from geography, the Italian School derives from the integration of architecture and urban design field. Compared to the former that emphasize the history of the city, the latter focuses on discovering the normative laws for the urban organism, which contributes to the development of typologies in the planning field (Cataldi, Maffei, & Vaccaro, 2002). Represented by S.Muratori, the Italian School was born in the ideological trend of "contextualism" as a reflection of the prevailing modernism in the field of architecture. The fundamental principle of their proposed "Typmorphology" is to unveil the inner mechanism of cities by analyzing the ichnography of buildings within a certain district with respect to different scales and period of history, based on which the decision of new urban development can be achieved for the purpose of retaining the cultural continuity. The research of Italian School was promoted by scholars including G.Ganiggia, P.Maretto, G.L.Maffei after S.Muratori (Lei Zhang, 2010). Nevertheless, the Italian School embraced little popularity in Chinese academia due to the lack of translated literature in Chinese or English, and the lack of direct communication with the School also impede the interpretation of the School (Chen, 2010).

The French School also emerges from the field of architecture. Over the years, the urban morphologists drew valuable research findings from sociologists like Henri Lefebvre, which later breed the pluralistic academic atmosphere in French urban form studies (Moudon, 1997). While the French School (Versailles School) center on the relationships between the social activities and urban form transformation (Chen & Thwaites, 2013, p. 57), there are many divergent branches from the mainstream morphological studies. On the one hand, the situation hinders the establishment of mainstream research of the Italian School; on the other hand, the situation enhances the expansion of researches of Italian School in terms of fields, objects, and methods (Lei Zhang, 2010).

The three schools generate numerous innovative research findings as well as methodologies to interpret the physical fabrics of cities. Kropf (2009) carried out a comparative analysis of the four symbolic morphological approaches in the field of urban morphology and summarized four broad types of an aspect of the built environment, including "spatial relations of physical features, interrelations between humans and physical features, flow, and change." It is noted that the majority of urban morphological studies subject to this categorization, and growing researches are contributing to refining it from miscellaneous aspects, both theoretical and methodological. For instance, Gauthier and Gilliland (2006), Oliveira (2013), and Ye and van Nes (2014) also contribute to synthesizing diverse hitherto researches regarding both theories and methodologies.

In recent years, these three schools have been thriving within their domains, and the traditional research methods have been widely applied and evolved endogenously. However, the methodology used to analyze and interpret the urban form are mainly qualitative and involve the subjective judgment by the researchers, which makes it hard to integrate different research findings as well as providing a detailed or precise explanation to the phenomenon (Oliveira, 2016). With the advancement of spatial analysis technology, emerging alternatives for assessing, classifying, and representing the spatial and socio-economic characters of the urban form have been widely adopted by “mathematical modelers” (Conzen, 2010, p. 56), who come from the multidisciplinary field including architecture, planning, geography, and engineering. Compared to the conventional methodology, which associates the diagram with the real built environment, this type of research focuses on the abstraction of the city and the algorithm underlying the urban modelling. The following section will further explore how to associate the theoretical framework of urban morphology with the empirical researches by introducing the hitherto research approaches both qualitative and quantitative.

2.2 Morphological approaches

Moudon (1997) identifies that although morphologists consist of scholars from different disciplines, they hold the same view that the built environment can be interpreted from a different scale using different approaches. The emerging Geographical Information Systems (GIS) is recommended by Moudon in the same paper since it provides urban morphologist with a quantitative analysis tool to represent the current characteristics of urban areas.

Oliveira's (2016) classification of main morphological approaches are built on Kropf's (2009) work. The four branches include historico-geographical approach, typological approach, space syntax approach, and spatial analytical approach. One possible way to perceive their connections is to place them in the evolution process of urban morphology regarding technology involved. The following section provides a general summary of the four approaches: historico-geographical, typological, space syntax, and spatial analytical.

2.2.1 Historico-Geographical Approach

The emergence of mature topological maps and city plans fostered the establishment of systematic research on urban form in the 18th century. According to Gauthiez (2004), the key theme of urban morphology is to analyze both the physical fabric of the city and the transformations happened to the city. The morphologists intend to unveil the inner mechanism of the force shaping the urban form from both static and dynamic perspectives by associating the social and economic activities to the built environment.

Urban morphologists of this approach tend to build a hierarchy of the city at different scales. The structure in the case of Alnwick is a tripartition, wherein the original town plan is divided into the street system, plot system, and building system, and the related socio-economic activities can be interpreted via the function of the space (Kropf, 2009). In addition, Conzen perfects the concept of "fringe belt" in his study on Alnwick and identifies three different belts which represent the transformative spatial process of the town. While the fringe belt denotes the uneven development of urban boundaries, Conzen also classifies the diverse processes regarding the formation and modification of the fringe-belt (Oliveira, 2016).

Sharing the same ontology with Conzen, Scheer (2001) put forward a "spatio-temporal hierarchy" by adding the time dimension. The fundamental argument is that in the changing process of a city, different systems (i.e., Street network, buildings, topography) change at a different speed. Consequently, the temporal function pertains to buildings or activities affiliated with space are not significant in shaping the urban fabric in the whole process compared to the street network or other systems with a higher level.

The primary research methods for historico-geographical approach include observations of the existing physical fabric and comparative analysis based on historical maps, plans, and photographs (Gu & Zhang, 2014). Research of this direction is primarily involved with the understanding of the urban form transformation process in a region from a perspective of historical evolution. For example, Morley (2012) systematically examined the development of the "modern urban form" in the Philippines from the early twentieth century under the force of American colonial and the "progressive civilization." Kim (2012) presented the influence of European morphological perspectives on the growth and evolution of South Korea's studies on urban form in chronological order and identifies the approach has been the most effective tool in interpreting South Korea's historical urban form transformation. Racine (2016) investigates the three urban design projects in Montreal from the morphological perspective in terms of their physical-spatial characteristics as well as their adaptation process in fitting into the broad historical urban contexture.

As the early stage of research on urban morphology, the approach shares the strength of the sound theoretical foundation and the drawbacks of descriptive nature. In recent years, the application of Geographical Information Systems (GIS) has contributed to the data acquisition and quantitative analysis process for urban morphology research, which can facilitate the historico-geographical approach as a complementary tool.

2.2.2 Typological Approach

The typological approach was first brought to urban morphology field by Italian architect Saverio Muratori, who expressed his understanding to the building type, urban fabric and urban organism in the *Studi per una Operante Storia Urbana di Venezia*, in 1959. The general idea of the typology can be interpreted as: first, there exists an *ideal form* for the built environment; second, the urban *types* at different level are formed through its inner constructive process isolated from spatio-temporal limitations; third, the city synthesizes all the types and present the physical urban form (Chen & Thwaites, 2013).

The typological approach was developed by Gianfranco Caniggia, who was one of the assistants for Muratori's team. According to Cataldi (2003), Caniggia contributes to the typological approach mainly by expanding Muratori's concepts, establishing the processual typology, interpreting the relationship between a city's history with the typological process. The scholars using typological approaches in Italy was recognized as Italian Typological School, and they conceive the city as more than an aggregation of physical objects, but diverse *types* and construction or transformation process behind the scene.

Following this research approaches, urban form is examined from a bottom-up lens, assuming the city as a system built up by fractional typological forms. Barke (2011) discovers a distinctive topological form, the multi-household dwelling (Corrales), and examines the birth and demise of this particular form as well as the urban development and urban planning policies pertaining to it in the city of Andalucia, Spain. The typological perspective also provides new insight into the local policy intervention process. Marzot, Cavallo, and Komossa (2016) delve into the urban form of the Netherlands regarding its leading role in the contemporary architecture field from the perspective of Italian typology. Maretto and Scardigno (2016) comprehensively investigate the urban form of the walled city of Ahmedabad in Indian with the adoption of Muratorian School, and systematically examines the typological process of the housing in the North Gujarat region. The research findings suggest the effectiveness of the typological approach in facilitating the understanding of the complex urban structure, both formal and informal.

Different from other approaches, the typological approach zooms into the scale of buildings in the city and focuses on the inner mechanism of the typology transition. The researchers applying this approach usually have a strong background in architecture. Therefore, they tend to view the urban form from the perspective of transitions leading by the individual types interspersed or clustered in the city. Due to the inherent epistemology of this approach, qualitative methods are dominant in the research process, and the diagrams of types are the most commonly used media to conclude and demonstrate the research findings.

2.2.3 Space Syntax Approach

Based on years of research, Hillier (2016) proposed a conceptual structure of the real city: the generic city. The idea is that the city is made up of a dual system wherein a “foreground network” is represented by long lines which can be abstracted as axial lines (Turner, 2007a), while the “background network” is consisted of numerous short lines emphasizing local interactions. This configurational difference is closely correlated with the social networks in the context of movement economies (Hillier, 1997) where “natural movement” is identified as spontaneous actions unaffected by attractors or magnets. By analyzing the natural movement (Hillier & Iida, 2005), the dual system of specific cities can be inferred and discussed.

The indicator to assess the spatial configuration of a city in the space syntax context is the accessibility. According to Batty (2009), accessibility can be defined in three categories: type 1 accessibility is defined as the proximity of an individual to opportunities; type 2 accessibility emphasizes the pure distance between two locations assuming opportunities are everywhere; type 3 accessibility defines the relationships between physical infrastructures by abstracting their links to a network model. The "accessibility" used in the space syntax is similar to the third type and focuses on the city network. Building on that, there are three metrics for the measurement in practice (Turner, 2007a), including Metric (least length), Geometric (least angle change), and Topological (fewest turns). With the additional lens on the scale (global vs. local), the space syntax can generate a comprehensive description of the study object. The space syntax approach arm the urban morphologists with a systematic and mathematical tool for understanding the urban form (Bafna, 2003).

The analytical methods of space syntax evolved from the original axial analysis (Turner, Penn, & Hillier, 2005) to angular segment analysis (Turner, 2007a) and then to the normalized angular choice (NACH) (Hillier, Yang, & Turner, 2012). Based on these instructive methods, the space syntax approach is fruitful in urban morphological researches worldwide. Can and Heath (2016) propose that social interactions are highly reliant on the connectivity of the streets, and the in-between spaces are crucial for the presence of the interactions. Zhu, Liu, Liu, Wang and Ma(2017) apply space syntax to understand the space in the Recreational Business District (RBD) and further explore the relationship between development and historic conservation in the RBD. Besides, Li, Xiao, Ye, Xu and Law (2016) integrated space syntax and spatial-temporal data representing tourists preference in the GIS platform, aiming at understanding the historic site as a tourism destination as well as providing recommendations for management and planning decisions. Space Syntax has thrived since its birth, and the future task for the field is to perfect the theory by emphasizing on regional scale analysis and social network exploration (Hillier & Shen, 2014).

Although the space syntax approach can provide a comprehensive analysis for the street network, it is constrained by the particular morphological aspect hence ignoring the implications of other morphological aspects such as density and diversity (Ye & van Nes, 2014).

2.2.4 Spatial Analytical Approach

The work of Michael Batty can be perceived as the representative trajectory of this approach since he is involved with a wide range of methods of urban modelling including GIS-based analysis, cellular automata, agent-based models, and fractals to understand the complexity of the cities. Batty describes the city as “problem” with “organized complexity” and is devoted to model the ‘problem’ to provide better description and prescription. Batty argues that the city should be understood as a dynamic process rather than a static object, which is justified by the modelling method transition from land-use transportation interaction modes to Cellular Automata (CA) and Agent-Based Models (ABM). The CA models have five main components, including the cells, the states of cells, the neighbourhood cells, the transition constraint, and the time. By setting these five indicators, the CA models can model the dynamic urban transformation, representing the pattern by the change of cells. Along with the development of CA, the ABM also has advanced. The ABM focuses on the simulation of individuals’ behaviour with the use of various agents, which are autonomous and heterogeneous entities such as individuals, buildings. (Oliveira, 2016)

Urban modelling using this approach has contributed to a series of urban studies. Al-shalabi et al. (2013) construct a CA model on the urban growth pattern and land-use changes for the City of Sana's (Yemen) in predicting the future urban development, which serves as an effective and robust tool for the local planning and decision-making process. In the same vein, Jjumba & Dragićević (2012) develop an agent-based model, the *Agent iCity*, to simulate the land-use changes that are influenced by the various stakeholders, thereby equipping urban planners with a better understanding of the land-use patterns. In addition, Zhong et al. (2014) try to detect the dynamics and complexity of the urban structure by introducing the most advanced research methods in network science to spatial analysis in Singapore. The research generates significant insights into the rapid urban transformation process in the current society where the spatial structure is continuously shaped by the ongoing and changing human movement patterns.

The spatial analytical approaches like CA, ABM, and fractals are different from other approaches in terms of how theory interact with the real world. For spatial analytical approaches, the theory directly influences the virtual model built-in advancing GIS platforms, based on which the real world is examined, and predictions are provided for the future. On the contrary, other approaches deal with the current and historical world, and the theories focus on concluding the past and solving the current issue. Moreover, the spatial analytical approach is heterogeneous because it is usually applied in the large-scale environment and with intended mathematical consideration. Therefore, the approach is commonly recognized as a complementary way in research on urban morphology.

2.3 Urban morphological research in China

While research on urban form - urban morphology - can be traced back to 1850s in Europe (Gauthiez, 2004), the same approaches applied to Chinese context only started in 1980s (Chen & Thwaites, 2013). The study of the urban form in China are facing challenges due to the following reasons: the independent socio-cultural background, the distinctive historico-geographical traditions (Conzen, Gu, & Whitehand, 2012), and the unique demographics and economic characteristics. Therefore, empirical research is essential for the purpose of better understanding the current morphological features of the typical Chinese cities.

The last decades have witnessed the indigenization process of urban morphological research in China through a distinctive perspective, including theory buildings, empirical practices, and interdisciplinary integration. As noted by Whitehand (2018), there is a significant increase in the numbers of articles from China in *Urban Morphology* in recent years, which indicates the growing interests in urban morphological studies in contemporary China. This section will briefly discuss the development in the field of urban morphology in China from the perspective of the four approaches, as mentioned earlier.

2.3.1 Historico-geographical

It was not until the 2000s when the historico-geographical approach, specifically the Conzenian methodology, was introduced to China. The early work can trace back to Gu's doctoral study on Hainan (Gu, 2002) where he identified *Danwe*i and "gated community" as the essential morphological elements in understanding the urban form transformation. Following the Conzenian School's tradition, Whitehand and Gu (2006) studied the urban landscape conservation of China's famous historic cities.

The primary gap for urban morphology studies in the early stage is the cultural discrepancy.

In addition, the scarcity of accurate maps and historic plans that represent the urban forms of different times is another challenge for morphologists (Gu & Zhang, 2014). Nevertheless, instructive researches have been undertaken in representative China cities, like Guangzhou, Pingyao, and Suzhou (Chen, 2011; Conzen, Gu, & Whitehand, 2012; Whitehand, Gu, Whitehand, & Zhang, 2011). Zhang (2015) explored the morphological transformation of the core area of Guangzhou in a long period ranging from distant feudal ages to now from the lens of Conzen's historico-geographical approach. He concludes that the Conzenian method is applicable in China, and the street network that been deemed as the most durable system in urban form remains unaffected during the process. Whitehand, Conzen and Gu (2016) undertook comparative research between the Chinese city, Pingyao, and the European city, Como. By adopting Conzenian approach, the study clearly demonstrates the historico-geographical structure of the two cities and shed light on the planning decision making process regarding historical conservation. Besides, Zhang and Ding (2018) expand the historico-geographic approach by adding the dimension of land occupation as a medium to interpret the urban transformations in the City of Nanjing.

However, urban morphology research in China is limited to large and more developed cities (Whitehand & Gu, 2006). Therefore, cities in western China are easily ignored due to the disadvantages of geographical location and local scholars' weak connection with mainstream urban morphology Schools.

2.3.2 Typological Approach

It is noted that Shen Kening (1988) first introduce the related theory to Chinese academia by introducing the theory and empirical work of Aldo Rossi, who coined the term "Analogue City" and apply the typology in the practice of architecture and planning since he deemed that the city can only be interpreted by associating with the long historical process that shapes it. The theory of typology enjoyed high popularity among Chinese scholars from architecture and planning filed. Later, the urban morphological researches are considered as more than descriptive methods, but effective solutions to the development of urban areas since the researches can generate a valuable reference for future (Chen, Yao, & Tian, 2017).

Compared with the Italian architect Aldo Rossi, Muratori and Caniggia were less known in China due to lack of their translated works (Deng, 2016). Therefore, the concept of "urban morphology" was considered to be analogous with "building typology" in the early adaptation process of typological approaches in China. In recent years, scholars who follow the Italian School's tradition aim to combine typology in understanding the urban issues of contemporary China. The proposed seven-element structure (Chen, 2010) and the theoretical frameworks guiding urban design (Chen & Thwaites, 2013) are successful examples demonstrating the value of the typomorphological approaches, especially in retaining the continuity and consistency of city image and urban design features in the long run (Chen, 2016). Li and Gauthier (2014) examine and reveal the morphogenetic process in the evolution of nineteenth-century residential buildings in Guangzhou by following the theories and methods of typological approaches. Nevertheless, the typological approach neglects the impacts of socio-economic factors since it focuses mainly on the transformation of patterns of buildings or urban context graphs.

2.3.3 Space Syntax Approach

Space Syntax was introduced to China in the 1990s with two early publications, *Space Syntax: A Different Urban Perspective* and *A discussion about 'Space Syntax Paper,'* in *New Architecture journal*. Later, with another two seminal books, *The Space Syntax and Urban Planning* and the Chinese version *Space is the Machine,* co-authored by Bill Hillier and Duan Jin, the theoretical principles as well as empirical studies shed light on the progress of research applying Space Syntax approach in China and significantly changed Chinese scholars' understanding of space from the perception that the space is the product of behaviours to the conception that urban form correlates with functions. It was suggested that Space Syntax had been recognized as a practical approach in urban studies when combining with other fields, including geography, sociology. The existing studies applying space syntax approach cover an extensive range of propositions. Liu and Yu (2012) explored the network accessibility of the Wuhan metropolitan area by investigating the classified space morphology from the perspective of space syntax. The findings suggest that the distinctive dimensions of urban form are interrelated and subject to the newly formed highway network. Wu et al. (2015) studied the permeability of the street and its relationship with the criminal pattern of residential burglaries in Wuhan, relying on the network analysis generated by space syntax approach. Also, Li et al. (2017) expand the application of space syntax approach in the study of assessing the accessibility of existing metro network in Xi'an and providing recommendations for planning decision making of metro network improvements.

Notwithstanding the fruitful status quo of this approach, the main challenges for the prospective application and research in China are the lacking of systematic understanding of the theoretical principles, which lead to the fallacy of misconception and misuse of the approach to analyze or predict the urban issues. The unprecedented urban changes in China and innovative technologies like GIS need to be explored and addressed in the future development of Space Syntax research in China (Duan & Hillier, 2015).

2.3.4 Spatial Analytical Approach

The spatial analytical approach can be perceived as a quantitative urban analysis method, the work of which is closely related to the "urban model." From the 1990s, the advancement of computer technology, artificial intelligence, and the Geographical Information System (GIS) promote the dynamic modelling of the urban areas, giving birth to the Cellular Automata (CA) model, Agent-based Modelling (ABM), and Fractals model (Lun, Ying, & Batty, 2015).

It is hard to trace the origin of the researches in this approach in China. However, the establishment of the Beijing City Lab (BCL) is a milestone in the progress of this approach in China. The major responsibility of BCL is to promote quantitative urban studies in China. The representative work of the BCL includes: applying a constrained cellular automata model to reconstruct the historical arable land-use patterns of Jiangsu (Long, Jin, Yang, & Zhou, 2014); evaluating the urban growth boundary of Beijing using big data (Long, Han, Tu, & Shu, 2015); understanding the change of urbanization patterns in China using the national population census (Qizhi, Ying, & Kang, 2016); identifying shrinking cities in China based on population data (Long & Wu, 2016); interpreting urbanization of China through analyzing the open data (X. Liu et al., 2015).

It is evident that the research related to urban form in China has progressed significantly in the past decades, but the infant state of the field will face threats and opportunities at the same time.

2.4 Research opportunities

2.4.1 New urban data

As mentioned before, the research opportunities of urban form come along with the new data environment derived from the advancement in information and communication technology. With the domination of the internet and digital devices in people's daily life, massive data regarding detailed societal activities have been recorded and restored in related databases. The new data environment facilitate the paradigm shifts in quantitative urban studies in four dimensions including: 1) spatial scale transformation from low resolution to high resolution; 2) temporal scale from static to dynamic; 3) transformation of research objects from land to individuals; and 4) methodology transformation (Long & Liu, 2017). Long, Li and Li (2018) proposed a classification framework of both new and tradition urban data in China (see Table 1). The classification may not cover all forms of urban data that are available in contemporary time, the diversity of data sources listed in the table indicates the large volume of datasets in place for urban researchers.

Table 1 *The classification of urban data sources in China*

	Categories	*Data Source*
New Data	Internet Data	POIs and road networks from AutoNavi or Baidu Map
		Open Street Map
		Weibo (equivalent to Twitter)
		Commercial websites such as online shopping, crowd-sourced forum, online advertising service, online search services
		Location Based Service (LBS)
	SmartCity Sensors	Urban infrastructures
		Real-time traffic map
		Taxi GPS
		Cell phones
Traditional Data	Remote Sensing	Nightlights from DMSP-OLS
	Statistics	Census data
		Planning documents
		Government archived data

Notes. Translated and reproduced from *Monitoring Built Environment of China with New Data: Indicator System and Case Studies,* by Long, Li and Li (2018, p. 89).

Amid these data sources, the Point of Interest (POI) data has been extensively utilized in urban studies. The point of interest data indicates the location of places that are deemed as the destinations that are interesting for people. The data contains two major types of information representing the location, including spatial information and its attribute as the social indicator. The multidimensional nature of the POIs data makes it difficult to visualize. Therefore, Yu, Ren, Du, Zhao and Nie (2013) proposed a new visualization method by integrating a digital cartographic model and digital landscape model, which facilitate the data mining in supporting the planning decision making the process. Long and Shen (2015) establish a model to differentiate zones with different functions by integrating POIs and the location-based smart card data that record the movement activities in the city, providing a new method for analyzing the dynamic urban structure. In addition to the city scale, Niu et al. (2017) focus on the identification of buildings functions by integrating multi-source ‘big data,’ including real-time location records, taxi GPS data, and POI data, with building footprint data in Guangzhou, China. The research findings indicate that the combination of multi-sourced urban data can provide more effective simulations of the urban environment. However, the classification of online POI databases is often not standardized; hence need a further filtering process before use. As such, machine learning technology is introduced in preprocessing the POI data by using the matching algorithm (Jiang, Alves, Rodrigues, Ferreira, & Pereira, 2015). It is noted that the POI data has been used extensively as an indicator of social attributes of the location, but little attention has been paid to the real objects that the POI data represents for in the city and how these locations contribute to the existing physical urban structure or the on-going transformation.

2.4.2 Emerging open data

The research on urban form and socio-economic activities related to it have been undertaken for long, while the evolution of the research approaches and research tools are limited by the medium to read the built environment – maps. However, in the past decade, the trend of Web 2.0 is leading a paradigm shift in terms of the data generation and data collection. The OpenStreetMap (OSM) emerged in this context and soon became one of the most successful Volunteered Geographic Information (VGI) projects (Fan, Zipf, Fu, & Neis, 2014). The OSM is a collaborative project that offers a free editable map for users worldwide where accredited users could update the map based on satellite maps or GPS tracks. In addition to the traditional map dataset, the crowd-sourcing can provide a mass of spatio-temporal data through various sources, including social media, the point of interests, and location-based services. These two datasets provide urban morphologists with information about their key research interests: the physical pattern of the urban fabric and the socio-economic activities pattern in the city. Furthermore, the crowdsourced data is an important complement to the conventional datasets generated from the top-down system and offers a new lens to understand the city organism.

Two limitations have been identified in traditional research on the relationship between urban form and function: the studies are limited by distinct time thereby not being able to provide comprehensive understanding to the complex dynamics; the authoritative datasets fail to include some informal settlement or emerging peripheral areas thereby neglecting valuable data representing sociocultural activities. Therefore, Crooks et al. (2015) propose a tabulated typology of comparison between traditional and crowdsourced form and function data by two categories of explicit and implicit. The crowdsourced contributions can be conducive to both explicit (directedly used) and implicit (secondary source) information. In recent years, researchers have used various crowdsourced data to interpret the physical fabric of the city. Liu and Long (2016) develop a method to identify parcels' boundary and their characteristics automatically by using OpenStreetMap (OSM) and point of interest (POI) data. Crooks et al. (2016) focus on how user-generated 'big data' can be harvested to contribute to the study of urban morphology. Liu et al. (2015) address the challenges in applying open datasets in understanding urban China and establish a crowdsourcing platform for gathering, storing and sharing open data of urban China.

While bringing numerous potential research opportunities, the crowdsourcing data faces the challenges in terms of quality. Feick and Roche (2013) identity that the absence of incentives, professional standards, and the suitable evaluation methods in the context of VGI is the main reason for the discrepancy of data quality. Recent studies have started to assess the quality of these crowdsourced data in contrast to the authoritative datasets. Fan et al. (2014) carried out a quality assessment to OpenStreetMap, specifically on building footprints data by comparing with ATKIS (German Authority Topographic-Cartographic Information System). The four indicators used in this research are completeness, semantic accuracy, position accuracy, and shape accuracy, based on which statistical analysis was undertaken. The conclusion is that the building footprints data is mostly accurate in terms of coverage while the attributes of the footprints data are lacking, and some buildings are missing. However, in general, the crowdsourced datasets are becoming comparable to the traditional datasets, thereby is credible to be applied in urban research.

2.4.3 Quantitative tools for morphological research

The advancement of spatial technology, especially on digital mapping, has provided more alternatives for urban morphologist to map, present, and visualize the physical world from the configurational perspective. The shift from qualitative methods to quantitative and mixed methods proceeds in the field of urban morphological studies. The mainstream contributions were made by Hillier (2007), Hoek (2008), Pont (2010), and Oliveira (2013), who establish theoretical frameworks for quantitative analytical approaches. In addition, innovative research software like Urban Network Analysis (Sevtsuk & Mekonnen, 2012), Form Syntax (Ye, Yeh, Zhuang, van Nes,

& Liu, 2017), and Depthmap (Turner, 2004), developed in recent years. Compared with the classic qualitative-oriented urban morphological research methods, the innovative quantitative methods make a breakthrough by ruling out the limitation of subjectivity.

The Urban Network Analysis (UNA) toolbox is developed by researchers from the City Form Lab of MIT. The tool provides urban designers and planners with innovative tools to better understand the "urban network", according to Sevtsuk (2013, p. 146), is an better representation of physical environment than other mediums like the plan because the plan while embodies rich elements of the built environment but lacks of the equivalent information about the spatial relationships between them. With the increasing availability of geographic data, the Urban Network Analysis can complement other network analysis packages by providing a free and open-source toolbox that can be operated in the ArcGIS platform.

The "Form Syntax" is developed in the situation where various methods (both qualitative and quantitative) have been developed to analyze the physical urban form while none of them is comprehensive and can be the representation to reveal at least most of the spatial features of the built environment. Based on the work on quantitative tools in urban morphology (Ye & van Nes, 2014), the "Form Syntax" (Ye et al., 2017) was proposed using GIS platform to integrate Space Syntax, Spacematrix, and Mixed-Use Index to measure three main properties of urban form: street-network configuration, density, and functional land use. Subsequently, the three results are combined and quantified through raster maps in ArcGIS, which contribute to the classification of urban properties in the dimension of urbanity. The concept of urbanity can trace back to Jane Jacobs's (1961) idea of street diversity and other scholar's emphasis on the vibrant living environment for people's interaction.

Besides these two, as a representative and most renowned quantitative tool of morphological research, Depthmap is rooted in the theoretical background of space syntax and is proposed by University College London. Within the last 30 years since the birth of space syntax, the method has gained international fame and has been applied in studies on architectural form, urban form and historical features (see works by Hui & Craig, 2017; Ramzy, 2016; Yu, Ostwald, & Gu, 2018). Notwithstanding the gradually increasing critics on the space syntax indicating the limitation of urban elements it focuses on, the method remains the most popular choice in the field of urban morphology analysis, considering it can quantify the spatial relationship between streets as well as affiliated social attributes. Compared to the other quantitative methods, the Depthmap has been proved to be a successful tool in analyzing the street networks of the city through numerous empirical studies in the last decades (see works by Hillier & Iida, 2005; Koohsari et al., 2016; X. Li et al., 2017; Porta, Crucitti, & Latora, 2006; Turner, 2007).

The Depthmap is built on Benedikt's work on isovist analysis (1979) and Hillier and Hanson's work on space syntax (1984). Sharing the same research topic on how movement patterns shaping the spatial space, the visibility graph analysis (VGA), was developed as the integration of the previous two analytical methods (Turner, 2003). By assigning different depth values to the nodes (representing the links between different elements), VGA builds an abstraction to the real system based on topological connections. While VGA is instrumental in evaluating interior space in the field of architecture, the analysis of the axial map that is another abstraction of convex space connections is specifically prepared for the city scale (Hillier, 2007).

The early Depthmap is designed exclusively for the conventional Computer-Aided Design (CAD) platform, which requires users to convert their data into Drawing Exchange Format (DXF) through AutoCAD. Since the software is based on topological measurements, it is hard to measure the objects in the process precisely. In recent years, with both GIS software development and the theoretical evolution bringing in metric and angular measurements, a new QGIS plugin, Space Syntax Toolkit (SST) was produced. Traditionally**,** the workflow of CAD users and GIS users are distinctive since they work with different data format. However, after the processing of Depthmap (DepthmapXnet in the GIS environment), the output can be used either for making diagrams or further explored through data analysis. The typical workflow of space syntax analytical research is summarized in Table 2 into seven primary steps, which can be extended to general quantitative urban morphological researches. According to the assertion made by Hillier (1997), the trick of correlating the numbers of observation with the numbers of spatial patterns can be generalized and promoted. As such, the SST is deliberately selected as one of the research tools of this research.

Table 2 *Generic workflows of Space Syntax Analysis*

	Operations
Data acquisition	Collecting, formatting, customized setting
Geo-processing	Join, transforming(fixing) geometries, attributes update
Network(Graph) Model	Draw map, generalizing road network, verification
Network Analysis	Space syntax, post process, morphology
Exploratory Spatial analysis	Visualization, spatial analysis
Statistical analysis	Descriptive statistics, L-regression, export
Reporting	Base map, resolution, colour range

Notes. Adapted from Gil, Varoudis, Karimi, and Penn's work (2015, p. 148:4).

Chapter 3: Methodology

According to Creswell (2014, p. 4), researchers' philosophy (worldviews) while not conspicuous can significantly affect research design, especially in terms of the selection of research approach and methods. The complexity of the city, as well as the ambiguity of urban form (Kropf, 2014), has become the major concern for urban morphologists. This research is guided by both constructivism and pragmatism for the following reasons. On the one hand, this research shares the same worldview with the constructivism, aiming at understanding the current urban form of Xi'an (the general world) and exploring the principles driving the urban fabric transformation process. This research also explores the possibility to utilize qualitative and quantitative methods both separately and collaboratively to interpret the factors affecting both urban form and socio-economic activities affiliated to it. The problem-centred and real-world practice-oriented nature is subject to the philosophy of pragmatism.

The mixed-methods approach is selected as the research approach for this research for the following reasons. First, the research topic "urban form in Xi'an" is of high complexity and cannot be interpreted exclusively through either qualitative or quantitative methods in the view of pragmatism. Therefore, the mixed methods approach is advantageous in terms of inclusiveness and comparativeness. Second, the field of the urban form is interdisciplinary, wherein scholars with diverse background use their specific lens to study and annotate the built environment. Furthermore, the findings by using a mixed-methods approach can fit into a broad range of further researches. However, this research weighs more on the quantitative analysis part, aiming to consolidate the findings from the qualitative methods through observation, case study and literature review.

3.1 Analytical framework

In this section, the analytical framework is proposed to respond to the research above questions (see Figure 1). This research adopts a mixed-method based on the theory of an exploratory sequential model (Creswell, 2014), which consists of three primary phases: the theoretical background, the empirical study, and the research findings.

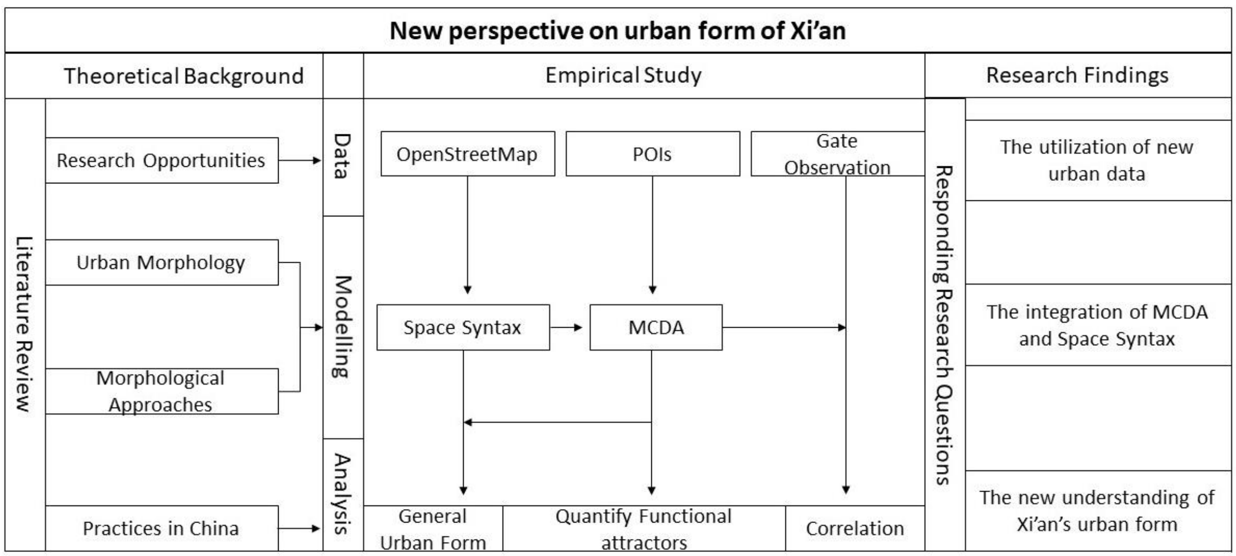


Figure 1 The proposed analytical framework for the research

In the theoretical background stage, this research explores the fundamental literature underpinning the research on urban form from four relevant aspects. These are the research opportunities, the urban morphology, the morphological approaches, as well as practices in China, which leads to the empirical study focusing on the urban form of the City of Xi'an. The empirical study is composed of three substantial aspects, including the data, the modelling and the analysis, each of which is derived from the corresponding theoretical background and subsequently responds to one of the research questions.

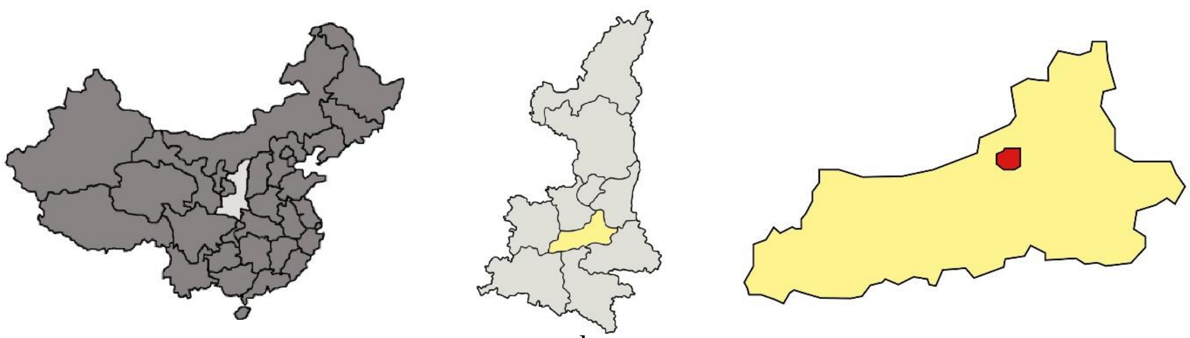
In the empirical study, a model of Xi'an (bounded by the second ring road) is built-in QGIS based on the street network data acquired from OpenStreetMap, and analysis was implemented through the space syntax approach, to unravel the general urban structure of the city of Xi'an. Subsequently, spatial attractors that affect the urban form and transformation were quantified using open datasets, precisely the POI data. Building on the analysis results of the urban form structure, the quantified attractors are introduced into the MCDA analysis process to generate a novel analysis result of the urban form. Finally, pedestrian movement data were collected through the conventional "gate count" observation method developed by the UCL space syntax laboratory as a parameter of the real world. With the two models (Space Syntax and MCDA) built in the previous steps and the observation data, two correlation analysis was undertaken to investigate the relationship among observed data and analysis results, followed by a comparative analysis of the research findings.

3.2 Research case

3.2.1 The case study of the city of Xi’an

3.2.1.1 Introduction

Xi’an (Western Peace), the capital city of Shaanxi province, is located on the Guanzhong Plain in northwestern China (Figure 2). Dating back to the Tang Dynasty (618 – 907 A.D.), eight rivers and streams surrounded the city. The abundant supply of water provides ideal conditions for the prosperity of the human settlement, which made the city of Changan (the alias of Xi’an) the world largest city at that time (Li & Zhang, 2012)



a b c

Figure 2 The geographical location of **a**. Shaanxi Province **b**. The city of Xi'an **c**. Study area.

The city of Xi’an is also home to several famous ancient capitals dating back to 11th century BC, including Fengjing and Gaojing (West Zhou dynasty), Xianyang (Qin dynasty), Changan (Western Han, Sui and Tang dynasties). With the historical legacy, Xi’an retains the main characteristics of the urban grid network (Figure 3) which is highly consistent with the urban planning philosophy for ideal capitals that was first appeared in “Kaogongji” in “Zhou’s Book of Rites” in the Warring States (475-221 B.C.) (Wu, 1986).

Due to the rapid pace of globalization and marketization after China’s reform and open-up policy in 1978, China’s large cities, especially the provincial capital cities, started the growth-oriented urbanization process driven by the central government as well as an economic boom. Three master plan directed the urban development of Xi'an to become an international megacity with a population of 8.8 million (Xi'an Statistical Yearbook, 2017) after the birth of People's Republic of China (PRC) in 1949. In 2017, Xi'an's GDP reached 746.9 billion yuan ($112 billion) with a year-on-year increase of 8%, ranking the 24th of all Chinese cities. The significant changes in the economic climate have affected many aspects of urban development, including infrastructure construction, property development, and landscape improvement.

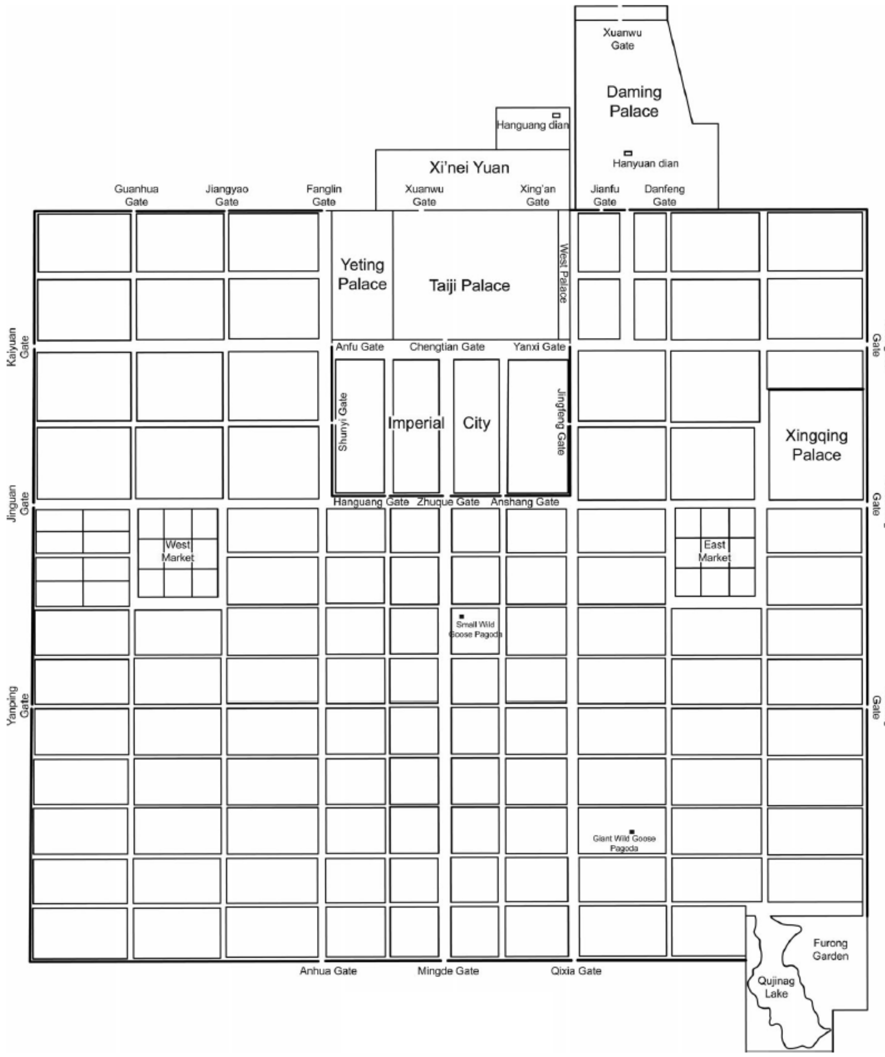


Figure 3 The grid network system of Chang'an during the Tang Dynasty. Sources: Li and Qian (2017, p.385)

3.2.1.2 The institutional changes

Government policy primarily leads to the urban development of Chinese cities. The open up policy in 1978 marked the objective of building China through economic development. In 1988, the establishment of a new land-use system facilitated the marketization of urban land, which gave birth to a land economy-driven urban development pattern. In 1992, a national “Socialist Market Economy System” was implemented and the establishment of “Sharing Tax System” in 1994 fostered the transition of the Chinese government to enterprises. Later, by joining the WTO, China embraced the globalization in 2001. The two driving forces of marketization and globalization contribute to various institutional changes in China, including the *Hukou* (household registration) system, the mitigation system, the housing system, as well as the urban development objectives (Wu & Gaubatz, 2013).

Besides the national level policies, the urban development of Xi'an was influenced by local policies. In 1984, the city of Xi'an was designated as one of the Municipalities with Independent Planning Status under the National Social and Economic Development policy (Liu et al., 2016), which started the urban and economic reform process. Following this, the establishment of "Xi'an New Technological and Industrial Development Pilot Zone" in 1988 and the approval of "Xi'an National High-tech Industrial Development Zone" in 1991 led to the new urban development pattern. In 2000, the "West Development Strategy" initiated the development process of China's western regions, which marks the onset of Xi'an's urban development. Nevertheless, compared to cities in the eastern coastal regions, the institutional reform burgeoned relatively late in Xi'an, hence making the city lagged in development regarding economy and urbanization.

3.2.1.3 A city in a dilemma

Once a prominent imperial capital city, the historical legacy has been a double-edged sword for the urban development of Xi'an in contemporary time. Embracing the opportunities introduced by the modernization process, the historic city is adapting its attitudes towards history, from demolition to conservation. As noted by Wu and Yan (2003), the trajectory of urban development and the whole process of urban development are analogous to a metabolic process that is continuously updated and transformed. The collective awareness of history and tradition plays a significant role in preserving the past as well as building the future. Similar to other historic Chinese cities, the issue of historical conservation has not been confronted until recently. Wang

(2000) identify that Xi'an has undergone numerous significant changes directed by the local planning authorities. During the transformation process, massive historical features and historic landscape has been wiped out, leaving a nominal historic city with some dispersively located historic sites and buildings. The city of Xi'an is currently in a dilemma of achieving a balance between economic development and historical conservation.

The third city master plan (2008-2020) adds a new dimension of Xi'an's heritage as a tourism industry. By promoting the cultural confidence in the urban development process, the city has proposed a sequence of plans intending to revitalize the old city center and restore the historic urban landscape. Zhu (2018) listed several visible accomplishments by Xi'an's municipal government in recent years, including the construction of Daming Palace archaeological park, the extension of inner-city streets to showcase the scale of old boulevards, and the re-emphasis on religion by nominating Buddhist buildings as World Heritage. By retrospecting and reusing the past, the city of Xi'an has made the firm progresses in urban development.

The current urban structure of Xi'an is outlined by three ring roads, with the old City Wall as the edge of the inner ring, the outer ring as the boundary between urban and suburban areas, and the intermediate ring as the transition (H. Li & Zhang, 2012). In this research, the areas bounded by the 2nd ring road are selected deliberately as the study area for two reasons. Firstly, this area covers the bulk of areas of the Tang Dynasty shown in Figure 3; and secondly the historic sites such as the Ming City Wall, the Bell Tower, the Drum Tower, the Forest of Stelae, and the Islamism Mosque are included, and the urban network of this area could reflect, to a certain extent, the historical tradition of other ancient Chinese cities. Besides, as recommended by the convention of modelling in Space Syntax, the ring road has the ability to split the urban network to independent subsections that each retains its intrinsic characteristics.

3.2.2 The selected districts

3.2.2.1 Introduction

To comprehensively examine the urban form of Xi'an, five distinctive districts was deliberately selected as local scale cases for this research for the purpose of quantifying attractor's impact on human's movement pattern. These five districts are among the most famous and popular districts within the second ring road of Xi'an, each consisting of several streets and representing a social dimension of the city. The intrinsic characteristics of the districts affect the structural formation process, hence creating various street network configurations as well as associated human activities associated. Different from the prevalent residential districts that primarily constitute the background network of the city (Hillier, 2016), the five districts server as the foreground network that could reflect the city making process driven by the microeconomic activities. In this section, the locations of the five districts and their background are introduced.

3.2.2.2 The selected districts

The selected districts include the Jiefanglu commercial district, the Shuyuanmen historic district, the Beiyuanmen Muslin district, the Tang West Market district, and the Dongguan district. As shown in Figure 4, the five districts are scattered within the 2nd ring road, and three of them are located within the 1st ring road (the Ming city wall). The five districts will be briefly introduced in this section in terms of their historical background and current situation.

The Jiefanglu commercial district is adjacent to Xi'an railway station, and the Jiefang Road is the city's arterial road that connects to the transportation hub. The high volume of passengers contributes to the area's vitality, which gives birth to a commercial-oriented neighbourhood. The Jiefang road was extended in 1952 and became the first concrete road in Xi'an (Shi, 2018). Nowadays, the district is home to several commercial complexes and a famous commercial node of the city.

Beiyuanmen and Shuyuanmen districts are both designated historic neighbourhood by the City (Qian & Li, 2017; Zhai & Ng, 2013). The Beiyuanmen, also known as Huiminjie (Muslim Quarter), is located in the center of Xi'an's city core and close to the Bell Tower and the Drum Tower. Historically as Muslim residential quarters, the site is now the most famous tourist

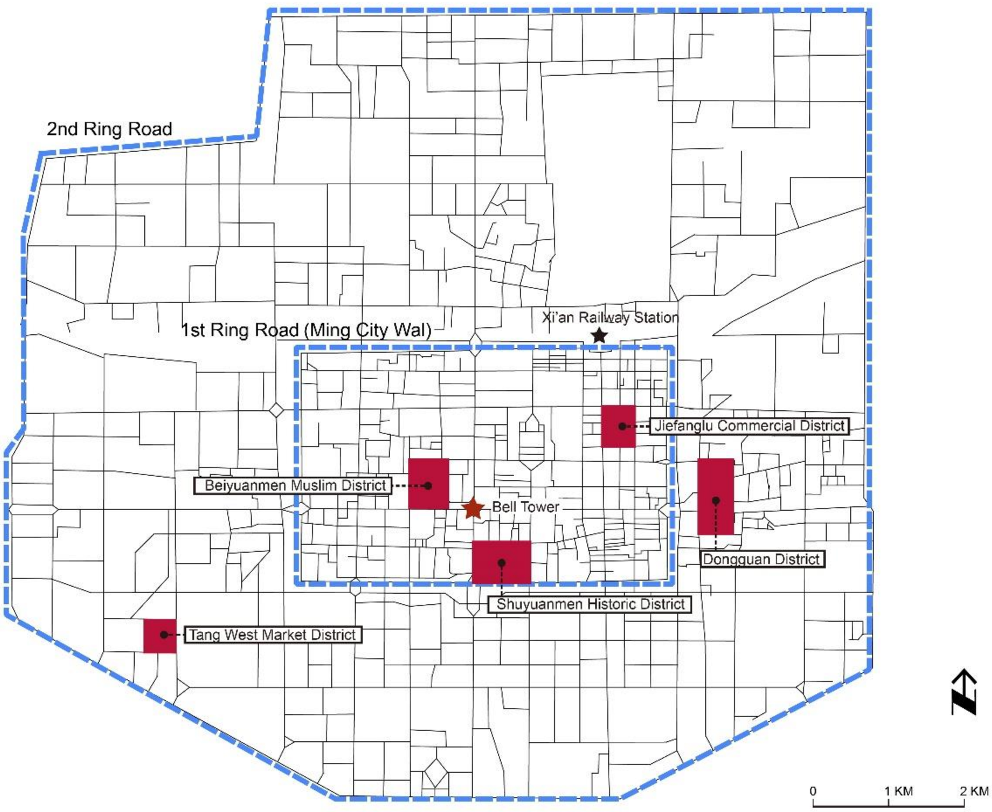


Figure 4 The spatial distribution of the five districts within the boundary of second ring road of Xi'an

attraction in Xi'an with its unique cultural activities and traditional food. The current architectural style of the district is restored based on that of Ming and Qing dynasty, and the infrastructures are well equipped according to modern standards.

The Shuyuanmen district is by the side of Xi'an's Ming City Wall and the South Gate. With a history of cultural and scholarly prosperity, the district is home to many historical sites such as the Guanzhong Academy, the Hua Pagoda, and the Stele Forest. The place is currently known as a cluster of cultural activities such as calligraphy and paintings as well as a gathering place of folk craftsmen. The increasing heritage tourism has brought a large population to the district, which contributes significantly to the local movement density.

The Tang West Market district is located in the southwestern part of Xi'an, on the historical site of West Market of Tang dynasty. In Tang dynasty, the place was an international trade market due to the proximity to the Kaiyuan Gate, the starting point of Silk Road. While destroyed in 835, the district was redesigned to inherit the spatial pattern and historical landscape of the Tang dynasty in 2005 (Bi & Wang, 2011). The current spatial layout of the district retains the "Jiu Gong" (nine palaces) pattern of the Changan city, and the primary functions of the place include open square space, antique market, retain oriented pedestrian zone, museum, and resort hotels. The district is an attraction for both tourists as well as local citizens of communities in the vicinity.

The Dongguan (East gate) district is the least known area in Xi'an compared with the previous four, but the place is one of the most dynamic and inclusive regions. The district is located east of the east gate of Ming City Wall and was the largest trade center in late Qing dynasty. Due to lack of proper planning guidance, the district is home to several shantytowns, where informal buildings are prevalent, and the accessibility of inner streets are relatively weak. There are two famous heritage sites located within this district, including the Tang Wangji Temple and the Song Baxian Palace. However, the preservation of these heritage sites is not satisfying with the fragmented and uncontrolled urban development (Tian, Xu, & Xu, 2016). In recent years, the local government initiated an urban renewal project aimed at transforming the district into a new urban center district encompassing diverse functions in the east Xi'an area.

3.2.2.3 Streets as the epitome of a city

The street network is one of the most symbolic aspects of the urban form. In addition to the physical configuration, the social attributes pertaining to people's daily life is closely related to and displayed by the streets. The street space is a container of human movement and social interactions, which generates valuable data for urban studies. On this account, the primary tool for gathering data in most urban studies is direct observation (Gehl & Svarre, 2013). The most seminal works related to urban street include, but not limited to, *The Death and Life of Great American Cities* (J. Jacobs, 1961), *The Image of the City* (Lynch, 1960), *Great Streets* (Jacobs, 1993) , *Life Between Buildings* (Gehl, 2011), and *Urban Design: Street and Square* (Moughtin, 2007).

In her book, Jacobs (1961) argued that the pedestrian activities on the street are the most significant indicators of cities' life, and six conditions are vital for maintaining the urban vitality, including land-use diversity, small block size, the mixture of buildings of different ages, the high-density development, as well as accessibility to urban amenities and the reduction of border vacuums (Sung & Lee, 2015). The theory has a substantial influence on subsequent urban planning theories and intrigued various research interests on the proposition of street and pedestrian activities. However, with the emphasis on mobility in contemporary cities, urban street planning has become transportation-oriented, and less attention has been paid to the purpose of place-making and catalyzing former and casual social engagement. Identified by Mehta (2013) as the quintessential public place for socializing, the streets record and demonstrate the history of the city. The streets are, among all the urban infrastructure, the most potent instrument in making the city comprehensible. The streets in the selected blocks in this research epitomize the city of Xi'an from both configurational and social dimensions, enhancing the interpretation of the urban form of Xi'an.

3.3 Datasets

This research is constructed primarily on three data sources, including the street network data from OpenStreetMap, the Point of Interests data from Baidu Map API, the human movement intensity data from the site investigation. This section presents the discussion of these three datasets regarding their general application, the acquisition process, and the description of data retrieved for this research.

3.3.1 OpenStreetMap (OSM)

3.3.1.1 Introduction

One of the significant paradigm shifts from the qualitative approaches to quantitative approaches in the field of urban morphology is the change of medium, maps that used to understand the urban morphology. With the advancement of information and communication of technologies (ICT), the ever-growing datasets of diverse forms are leading the emergence of theories and experimental works on cities, including the understanding the city's urban form (Batty, 2012). The recent years witnessed the success of OpenStreetMap (OSM) as a crowdsourcing platform and its potential to generate more than cartographical datasets (Fan et al., 2014).

The OpenStreetMap (OSM) project was started in 2004 to establish a platform for map editors with a diverse background to mapping the real world, hence providing an open map dataset for people. While traditional geodata was limited only to governmental agencies, cartographic institutions, as well as commercial organizations, the internet and inexpensive GPS trackers on people's portable devices made the geospatial datasets increasingly available. As the name indicates, the map initially consisted of roads and streets as the primary objects and subsequently introduced a brand range of geospatial objects such as buildings, land use information (Jokar

Arsanjani, Zipf, Mooney, & Helbich, 2015). OSM-related research has become the foci of many urban studies, and this potential has not been mined deep enough.

However, OSM is not widely accepted in the Chinese context, and the data quality is under doubt. Zheng and Zheng (2014) assessed the data quality of OSM in China and found that 66% of the OSM in China are correct and international cities like Beijing and Shanghai have more complete and positional accurate data compared to their counterpart cities. Notwithstanding these concerns, OSM data has been improved and applied in Chinese studies over the years (see, for example, Lin, 2018; Zeng, Yang, & Dong, 2017; Zhang, Li, Wang, Bao, & Tian, 2015). Therefore, the cartographical resources provided by OSM are the most valuable instrument for analyzing the urban form of Chinese cities, since Gu and Zhang (2014) noted that these datasets are strictly limited in Chinese institutional system with the consideration of confidentiality and national security.

3.3.1.2 The OSM data of Xi'an

The raw data acquired from OSM of Xi'an serves as the primary reference for the network model building in our research. The Hot Export Tool (https://export.hotosm.org/) was utilized to download the filtered OSM map from the website. The tool is designed to equip users with more accessible and handy ways to extract data from OSM to the local desktop. The tool has a specific step-by-step guide on how to download the map datasets of the user's target area. It provides various types of file format, including, but not limited to, Shapefile(.shp), GeoPackage(.gpkg), Garmin(.img), Google Earth(.kml), OSM(.pdf). In terms of the geometry types, the tool offers a filter based on the tag of the objects which classify the geometries into different categories such as buildings, commercial, education, transportation, land use. As shown in Figure 5a, the data retrieved from OSM is bounded by a specified square, and the total number of features is 3787.

However, since this research focuses on the city-scale road structure, the objects with attributes like “cycleway” and “footway” are dropped during the data cleaning process. These objects are first selected by implementing “selection by attributes” function in QGIS and subsequently deleted with the activation of layer editing, later generating a new street network with fewer features at 2390 (Figure 5b).

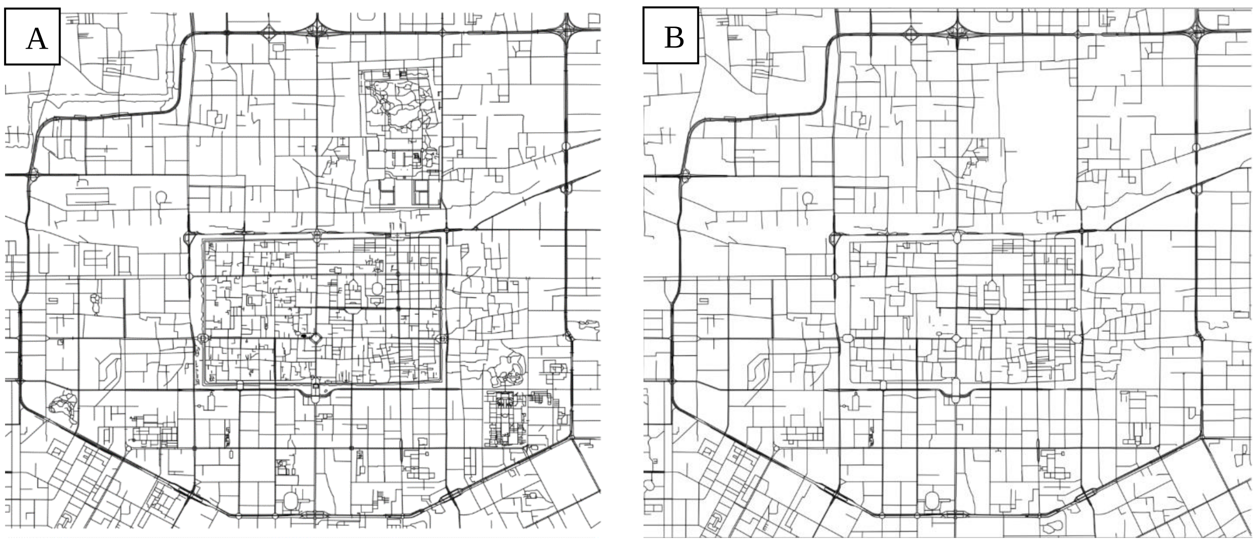


Figure 5 The OSM data of Xi’an. **A** The raw data retrieved from the OSM. **B** The street network of Xi’an after filtering.

Considering the OSM is not widely accepted in the Chinese context, and there may be inaccurate topological connections. To validate the Space Syntax model created based on the OSM data, samples of the street network from Baidu Map (equivalent to Google Map in China) were manually selected as a comparison. Besides, it is noteworthy to mention that the default coordinate system of the OSM map is the WGS-84 which is different from the that of Baidu Map (BD09). Therefore, all the spatial datasets used in this research are converted into the WGS-84 coordinate system, and the projection of the data frame is set into Beijing 1954 3-degree Gauss-Kruger CM 108E.

3.3.2 Point of Interest (POI)

3.3.2.1 Introduction

The POIs represent all the geospatial entities that can be abstracted to points with information regarding their names, land-use function, addresses, as well as the georeferenced coordinates. These spatial locations are mainly defined by the users of a certain web platform who identify these points based on their perspectives. As pointed out by Li, Li, Yuan and Li (2019), the classification of POIs in China usually confirm with the land-use categories. Therefore, the POIs have the potential to imply the user's preferences and social activities. In addition, according to Wu, Ye, Ren and Du (2018), while the POI classification reflects the land-use categories in China, the POI data are advantageous to the latter with three primary merits: 1) the flexibility in study scale issues; 2) the close relationship with people's social functions and activities; 3) high level of statistical granularity that providing more useful information. Oftentimes, the POI data are implemented in combination with VGI (Volunteered Geographic Information) data to reveal more comprehensive individual social activities.

It is noted that from 2014, China embarked on rapid development in utilizing big data in urban studies and planning process (Hao, Zhu, & Zhong, 2015). Among the extensive range of big data types, the POIs, with its intrinsic bottom-up nature and multi-dimensional features, have been applied in a considerable number of urban studies, covering broad research areas, including but not limited to the following: urban boundary delineation, urban agglomeration process, inner-spatial structure identification, urban function division, planning implementation evaluation, and smart transportation systems (Hao et al., 2015; Lan, Yu, Xu, & Wu, 2018).

The recent studies showcase strong interests in integrating POI data with other forms of data to provide a comprehensive lens on the research topic. Liu and Long (2016) propose a vector-based cellular automata model to automatically identify land parcels by integrating OSM and POI data in mitigating the issue of urban parcels information paucity in China. The novel method has been proven to be able to generate consistent results compared to conventional land parcel data. Long and Shen (2015) establish a specific model called “Discovering Zones of different Functions (DZoF)” based on the Smart Card Data (SCD) and POI to highlight the main function of a urban area and unravel the generic spatial structure of the city, providing valuable planning background information for urban planners as well as governmental decision-makers. Besides, as one type of emerging big urban datasets, the POI data in collaboration with multi-source big datasets has been utilized in research on identifying building functions (Niu et al., 2017). The research also suggests that multi-source urban data can provide a more comprehensive and useful representation of the real urban complexity. As such, the POI data that represents the attractors scattered in the city is applied in association with OSM data as well as observation data to make contributions to the investigation of the urban form of Xi’an.

3.3.2.2 The POIs data of Xi’an

The Baidu Map offers a web map API (http://lbsyun.baidu.com) for registered developers to acquire various spatial services such as POI search, Geocoding, IP location, route planning, streetscape service, and trip trajectory service. A python snippet (see Appendix A) was written to automatically get all the POI data bounded by a box that covers areas within Xi’an’s 2^{nd} ring road. As shown in Table 3, the original classification of the POIs consists of two tiers, and the first tier includes 19 types that cover a broad range of land-use functions. Among all these classifications, four main first-tier classifications were deliberately selected to further implement MCDA analysis, namely the catering service, the commerce, the tourist attraction, and the transportation facilities. These four indicators have been extensively examined by scholars in urban studies (Lan et al., 2018; Mansouri & Ujang, 2017; Turner, 2007b; Wang, He, Jiang, & Li, 2018), thus been the appropriate representation of urban attractors in this research. A total of 14,959 geotagged POIs were retrieved from the web service, and the data quality was gauged manually with randomly selected samples. The further application of the POI data will be introduced in the subsequent sections.

Table 3 *The two tiers classification of POIs*

First Tier Classification	*Second Tier Classification*
Catering Services	Chinese restaurant, Foreign restaurant, Fast-food, Bakery and dessert shop, Coffee shop, Teahouse, Bar
Hotel	Star-rating hotels, Express hotel, Apartment hotel
Commerce	Commercial hub, Department store, Supermarket, Convenience store, Home furnishings retail, Electronics retail, Shops, Market
Facility	Operator's store, Post office, Logistics company, Tickets sale, Laundry, Print shop, Film store, Real-estate agency, Home services, Funeral services, Lottery retailer, Pet service, Newsstand, Public toilet
Beauty Salon	Cosmetology, Hair salon, Nails salon, Body Shaping
Tourist Attraction	Park, Zoo, Botanical garden, Amusement park, Museum, Aquarium, Seaside, Cultural heritage, Cathedral, Scenic area
Leisure	Resort, Rural tourism, Cinema, KTV, Theatre, Dance hall, Internet Café, Game spots, Spa center, Recreational square
Fitness	Gym, Extreme sports venue, Fitness center
Education and Training	Higher education institution, High school, Primary school, Adult education, Parent-child education, Special education schools, Overseas education agency, Institutions, Research Institute, Training agency, Library, Technology museum
Culture Media	News(publishing), Broadcasting, Art group, Art gallery, Exhibition hall, Cultural center
Medical Care	General hospital, Specialists hospital, Clinic, Pharmacy, Medical examination institution, Nursing home, Emergency center, Centers for disease control and prevention
Auto service	Auto sales, Auto repair, Auto maintenance, Car accessories, Car rental, Vehicle inspection
Transportation Facility	Airport, Railway station, Subway station, Subway lines, Intercity bus terminal, Bus station, Bus lines, Port, Parking lot, Gas station, Motorway toll stations, Bridge, Charging station, Roadside parking
Finance	Bank, ATM, Credit Union, Investment agency, Pawn shop
Real Estate	Office building, Residential quarter, Dormitory
Company	Company, Industrial park, Agriculture and forestry, Mining Factory
Government Agency	Central institution, Government office, Administrative unit, Public security agency, Foreign-related institutions, Party organization, Welfare agency, Political and educational institution
Road Entrance and Exits	Highway entrance, Highway exit, Airport entrance, Airport exit, Bus station entrance, Bus station exit, Gate, Parking lot entrance and exist
Natural Features	Island, Mountain, River

Notes. Translated from Baidu Map API (http://lbsyun.baidu.com/index.php?title=lbscloud/poitags)

3.3.3 Gate observation

3.3.3.1 Introduction

The technique of "gate observation" was developed by the UCL Space Syntax Laboratory and was first introduced in the *Space Syntax Observation Manual* (Grajewski & Vaughan, 2001). As mentioned before, the observation as a technique has been extensively applied in urban studies to collect data regarding human dynamics and social interactions. Under the assumption that human movement in the city is a collective and independent natural activity (Hillier et al., 1993), the method of observation enables researchers to objectively perceive the human actions as well as the built environment. In addition to observation, methods like photography, surveys, questionnaires, and interviews generally work in collaboration with observation to facilitate the findings.

As shown in Figure 6, the observer who conducts the gate counts stands at one side of the street so that both passing pedestrians and vehicles are within the observer's visual control. Each observation session usually lasts for 5 or 2.5 minutes, depending on the density of adjacent gates and the intensity of local movement activities. The number of pedestrians and vehicles that cross the imaginary line (the visual line of the observer) during this period will thereby be noted to a predesigned table (see examples in Appendix B). To reduce human errors when counting the numbers, the observer may use a stopwatch or similar devices to facilitate the procedure. Additionally, to help researcher's interpretation of the data, the qualitative description of the environment of the street and surroundings concerning the traffic, climate, functions, may also be documented in or beside the table. In general, a reasonable number of gates selected for a specific study area should be around 25, and a single gate could be further divided into more sub-gates, considering the unexpected dense human flow.

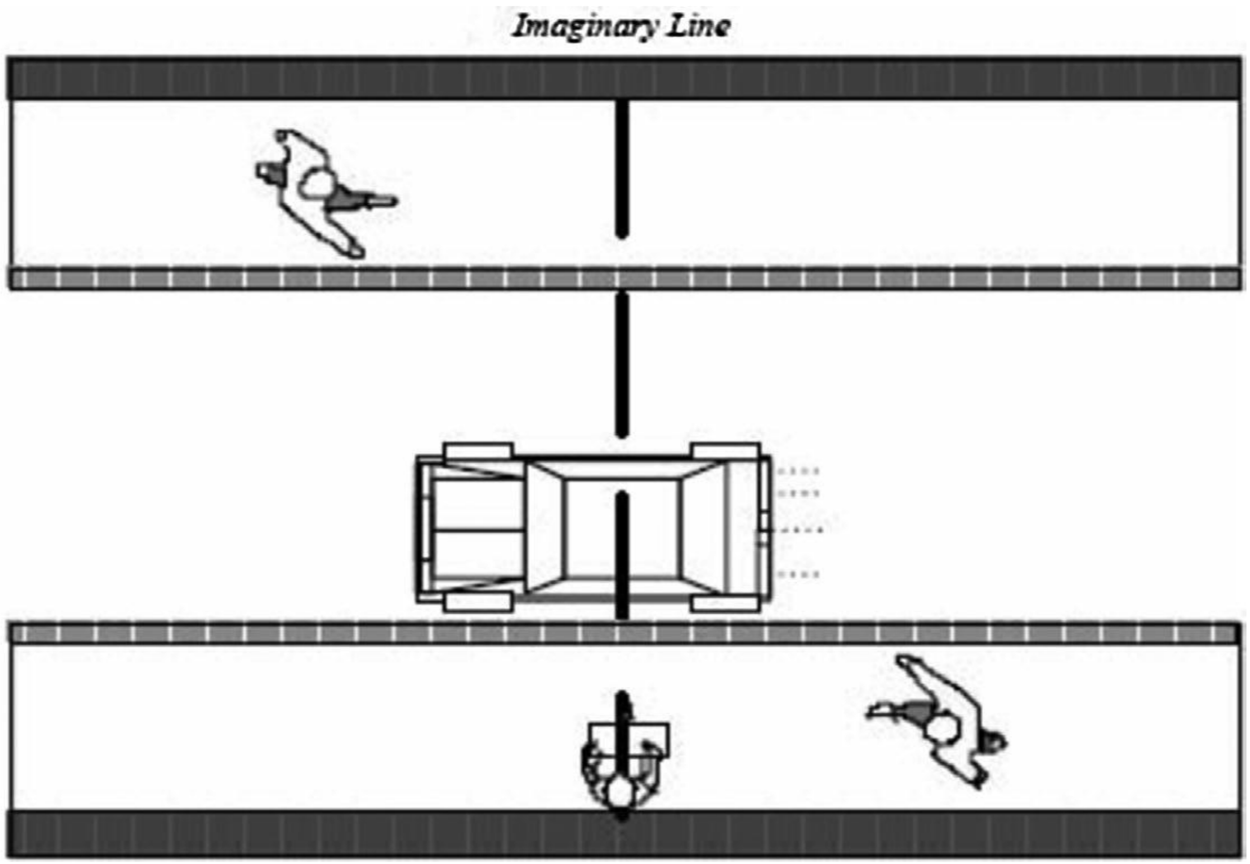


Figure 6 The gate observation method (Source: Al-Sayed, 2018, p.42)

3.3.3.2 The implementation of gate observation

It is recommended in the space syntax manual that a preliminary field survey should be carried out for the preparation of the gate counts to make the observers familiar with the surroundings. As illustrated in Figure 7, a total of 8 gates were deliberately selected for each of the districts except for Dongguan district (5 gates) where the on-going infrastructure construction during the observation period impeded the data collection. The selected gates could cover the bulk of streets in the area that represent "a range of well-used, moderately-used and poorly used spaces in and around the boundaries (Al-Sayed, 2018)." It is worth mentioning that there are no actual boundaries associated with the five selected districts, so the blue dashed lines shown in Figure 7 are exclusively the assumed boundary. The number of pedestrians who passed through the imaginary line in a period of 5 minutes was recorded to the predesigned form. The observer takes turns counting the pedestrians at the 8 locations in three different periods (11:00-12:00, 15:00-16:00, and 18:00-19:00) on weekdays except for Friday, since Friday may generate outliers in terms of the intensity of pedestrian flow because people may congregate to these districts for recreational activities on Friday.

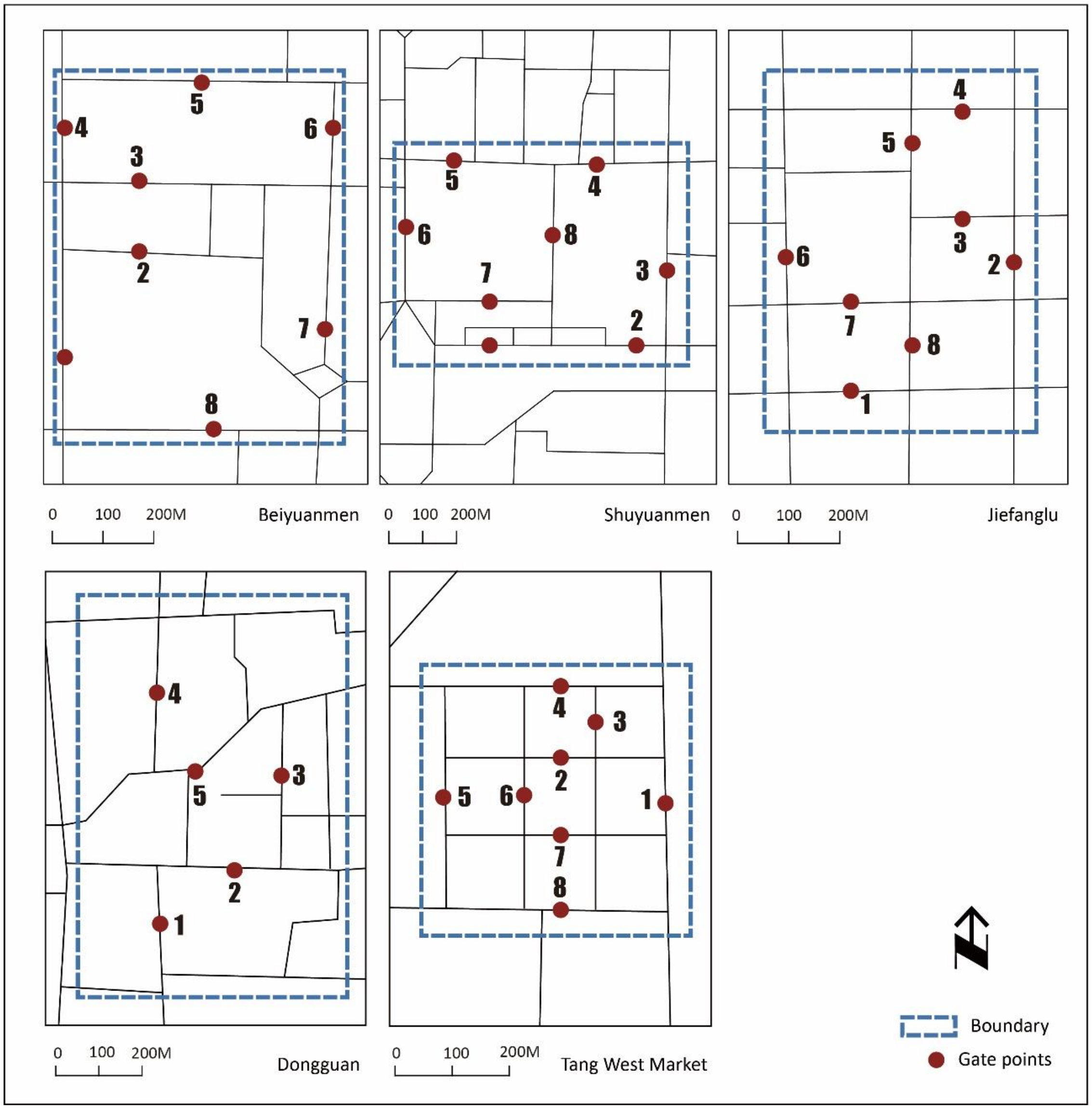


Figure 7 The network boundary and the location of gates in the five districts

The results of the gate counts are presented from Table 4 to Table 8. According to these tables, it is apparent that the five districts share similarity regarding the distribution of the number of counts in the three periods of observation. The period of 18:00-19:00 has the most substantial pedestrian intensity and, on the contrary, the period of 15:00-16:00 has the lowest. In terms of the total volume of pedestrian of the five districts, the Beiyuanmen district is passed by most people while the West Tang Market district is the opposite. The further interpretation and implementation of these observation data will be elaborated in the next section.

Table 4 *The gate counts of the Jiefanglu district*

	G1	G2	G3	G4	G5	G6	G7	G8	Total
11:00-12:00	36	34	23	82	64	152	40	89	520
15:00-16:00	28	26	25	92	90	116	54	51	482
18:00-19:00	40	52	35	122	149	262	85	98	843
Total	104	112	83	296	303	530	179	238	1845

Table 5 *The gate counts of the Beiyuanmen district*

	G1	G2	G3	G4	G5	G6	G7	G8	Total
11:00-12:00	151	10	151	96	68	296	327	90	1189
15:00-16:00	107	6	58	31	33	217	265	90	807
18:00-19:00	230	22	282	163	144	565	602	150	2158
Total	488	38	491	290	245	1078	1194	330	4154

Table 6 *The gate counts of the Shuyuanmen district*

	G1	G2	G3	G4	G5	G6	G7	G8	Total
11:00-12:00	20	23	32	64	73	130	78	57	477
15:00-16:00	18	15	52	62	58	182	73	38	498
18:00-19:00	26	54	96	90	111	262	111	53	803
Total	64	92	180	216	242	574	262	148	1778

Table 7 *The gate counts of the West Tang Market district*

	G1	G2	G3	G4	G5	G6	G7	G8	Total
11:00-12:00	50	51	6	25	16	9	16	24	197
15:00-16:00	32	41	15	3	24	4	10	19	148
18:00-19:00	87	44	31	51	26	27	49	46	361
Total	169	136	52	79	66	40	75	89	706

Table 8 *The gate counts of Dongguan district*

	G1	G2	G3	G4	G5	Total
11:00-12:00	91	194	54	18	32	389
15:00-16:00	61	142	53	15	6	277
18:00-19:00	91	152	110	43	49	445
Total	243	488	217	76	87	1111

3.4 Space syntax analysis

The space syntax analysis is a theory-based analytical and design technology in the field of urban planning. Based on years of research, Hillier (2016) proposed a conceptual structure of the real city: the generic city. The idea the city being made up of a dual system wherein a "foreground network" is represented by long lines which can be abstracted as axial lines (Turner, 2007a), while the "background network" consists of numerous short lines emphasizing local interactions. This configurational difference is closely correlated with the social networks in the context of movement economies (Hillier, 1997) where "natural movement" is identified as spontaneous actions unaffected by attractors or magnets. By analyzing the natural movement (Hillier & Iida, 2005), the dual system of specific cities can be inferred and examined. Building on the theory, a strand of literature concentrates on explaining and predicting human movement through the lens of Space Syntax (see, for example, by Law, Sakr, & Martinez, 2014; Lerman, Rofè, & Omer, 2014; P. Liu, Xiao, Zhang, Wu, & Zhang, 2018; Mohamed, 2016). As identified in a recent study (Hillier, Yang, & Turner, 2012), the normalized angular choice (NACH) is proved to be the hitherto most effective indicator in estimating the movement flows through space. Therefore, the NACH serves as the primary parameter in the analytical process of this research.

Before delving into the common indicators in the space syntax analysis, an example of how an urban area is represented in space syntax model is presented in Figure 8. By converting the urban spaces into axial lines as well as the topological graph, the urban area can be quantified, and the connectivity of each line (road) can be calculated.

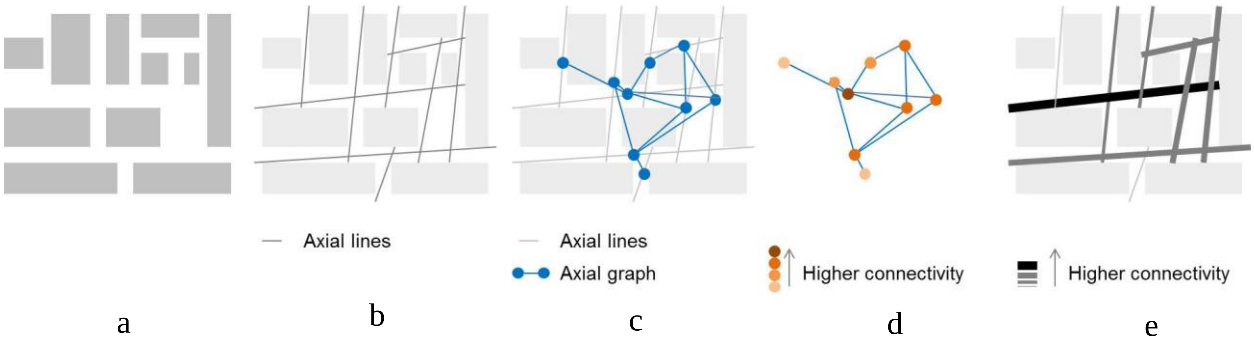


Figure 8 The representation of an urban space in Space Syntax. **a** the urban space. **b** represented by the fewest and longest axial lines covering the convex space. **c** topological graph. **d &e** the symbology of connectivity (Al-Sayed, 2018, p.12).

Although the axial map has been proven to be an effective way to forecast underlying movement activity in the urban area, limitations have emerged with more empirical studies. There is an increasing need to measure linear or semi-linear connections in cities that have a uniform structure. It is under this situation that a fine-grained measurement was introduced to space syntax analysis – the segment representation. The segment in space syntax context refers to a segment between two intersection points. While the segments can be measured by cumulative angular changes between them, the angular depth method has become a successful alternative for space syntax analysis. According to Hillier and Iida (2005), angular analysis is effective regarding spatial navigation and wayfinding.

3.4.1 The common indicators of measurement

The space syntax approach focuses on the typological relationship between different spaces. One of the fundamental concepts in space syntax is that the axial map, which is defined as the longest line that dominates the convex space, be accessible and visible from any place within the space. On the city scale, the urban street network could be abstracted to a topological graph, where the vertices represent the axial lines, and the lines represent the connections between two axial lines.

The rudimentary concept in Space Syntax is the depth of spaces. The depth (topological distance) is defined as the syntactic steps between two spaces in the abstracted topological graph, such as the direction change in the axial map. As a topological measurement, the depth has no geometric attributes. The commonly used graph measures (refer to Al-Sayed, 2018) are listed as follows:

- The Total Depth (TD) measures the topological distance between different vertices with the target vertex. The TD of vertex i is the summation of all depths from another vertex k to i.

$$\mathrm{T}D_i = \sum_{k=1}^{n-1} d_{ik}\,, \quad i \neq k$$

Where the n is the total number of the axial lines in the system.

- The Mean Depth (MD) is the mean of the TD of a specific vertex i.

$$\mathrm{M}D_i = \frac{1}{n-1}\sum_{k=1}^{n-1} d_{ik}\,, \quad i \neq k$$

- The Relativized Asymmetry (RA) measures the centrality of an axial map by comparing its MD with the MD of the total system.

$$\mathrm{R}A_i = \frac{MD_i - 1}{\frac{n}{2} - 1}$$

- The 'Dimond' D-value is proposed by Kruger (1989) to normalize different topological graphs for comparison between systems.

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

- The Real Relative Asymmetry (RRA) is the normalized RA

$$\text{RR}A_i = \frac{RA_i}{D_i}$$

- The Integration (INT) is one of the fundamental indicators in determining the centrality of a specific axial line in a system, often refers as the Centrality Closeness or Betweenness (Freeman, 1977). In urban-related research, the high value of INT indicates that more people are likely to gather in the space, which may generate social interactions and activities such as retail.

$$\text{INT}_i = \frac{1}{RRA_i} = \frac{D_i}{RA_i}$$

- The Choice (CH) is another rudimentary indicator of space syntax analysis, also refers to Betweenness Centrality. The CH measures how often a vertex is used as a path for connections between all different origins and destinations of the graph system. In urban-related studies, the CH value is considered to correspond with movement flows through spaces. Therefore, it is widely used to predict human movement potentials in urban areas.

$$\text{C}H_i = \frac{\sigma_{s,t}(i)}{\sigma_{s,t}}$$

- The Normalized Angular Choice (NACH) is a novel choice measure method which normalizes the Choice value on the angular basis.

$$\text{NACH} = \frac{\log(CH + 1)}{\log(TD + 3)}$$

3.4.2 Map modelling

The initial step of map modelling in space syntax is to draw an axial map that represents the same study area of the research. Based on the OSM street network map generated in the previous step, the urban structure of the city of Xi'an is translated into the axial map in the software of Autodesk AutoCAD. The predominant principle in drawing the axial map is to reduce both the number of lines and the angular alteration between two lines. Also, all the abstracted roads should be at the equivalent level, meaning all the road network inside a certain area that is not open for all citizens are excluded, such as the roads bounded within a gated residential quarter, a gated university, or gated institutions. As shown in Figure 10a, the end of two intersected lines is expected to extend for a certain length that less than 25% of the total length.

The next step is to export the map in the DXF file and import it into QGIS platform. The conventional software for performing space syntax analysis is the DepthMap, but with the invention of Space Syntax Toolkit (SST) for QGIS that developed by the Space Syntax Laboratory at UCL, the GIS-based work environment is becoming prevalent in related studies. After undertaking network generalization, map verification, and unlinks check (see work by Gil et al., 2015b for more details), the imported axial map is ready for network analysis. The analysis dialogue is presented in Figure 9, from where the user is able to set the target layer, the analysis method (axial or segment), and the radius of the analysis. By checking the segment option, the axial map will be automatically converted to a segment map (Figure 10b) with no extension at each intersection and the long axial lines are divided into several segments according to intersections. Besides, the axial stubs that are less than a specified percentage in settings (25% for this research) will also be removed. The residual segments outside the second ring road are also removed manually from the axial map for the consideration of no unnecessary depth being introduced to the analysis. Compared with the axial map, the segment map representation of the city spaces is more effective in dealing with the semi-continuous lines of the system since the segment can denote the cumulative angular change between different intersecting streets, which is a robust indicator in angular depth measurement to revealing configurational features of the urban network.

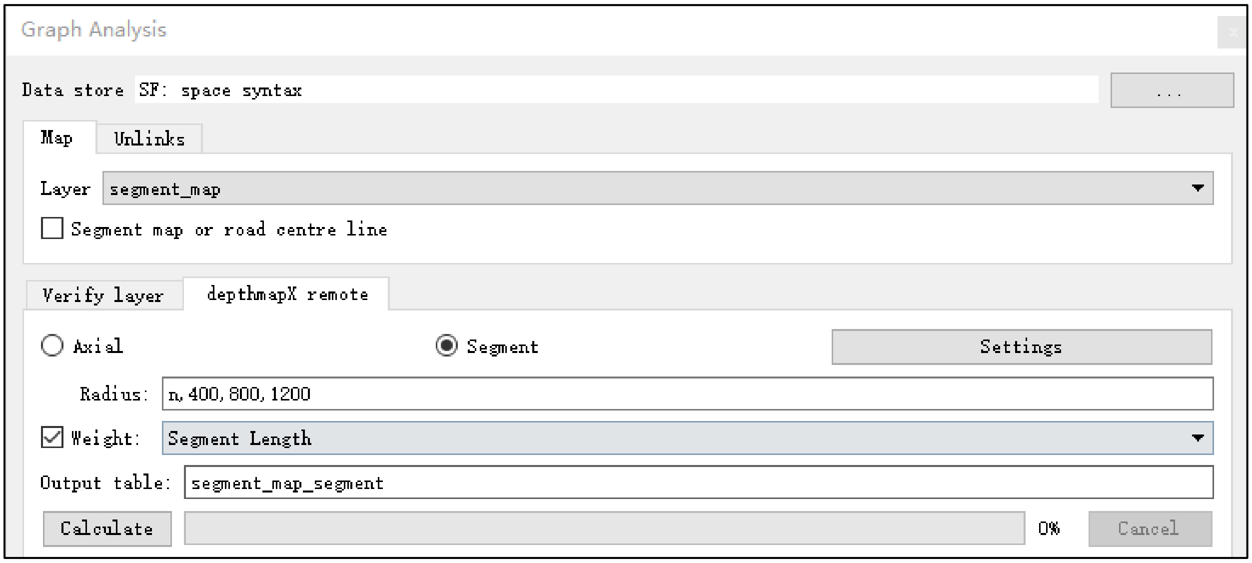


Figure 9 The space syntax analysis toolkit dialogue in QGIS

The segment map has 2167 segments in total, with the longest segment at 1420 meters, and the mean length at 201 meters. The result of the space syntax analysis will be demonstrated and explained in the next chapter.

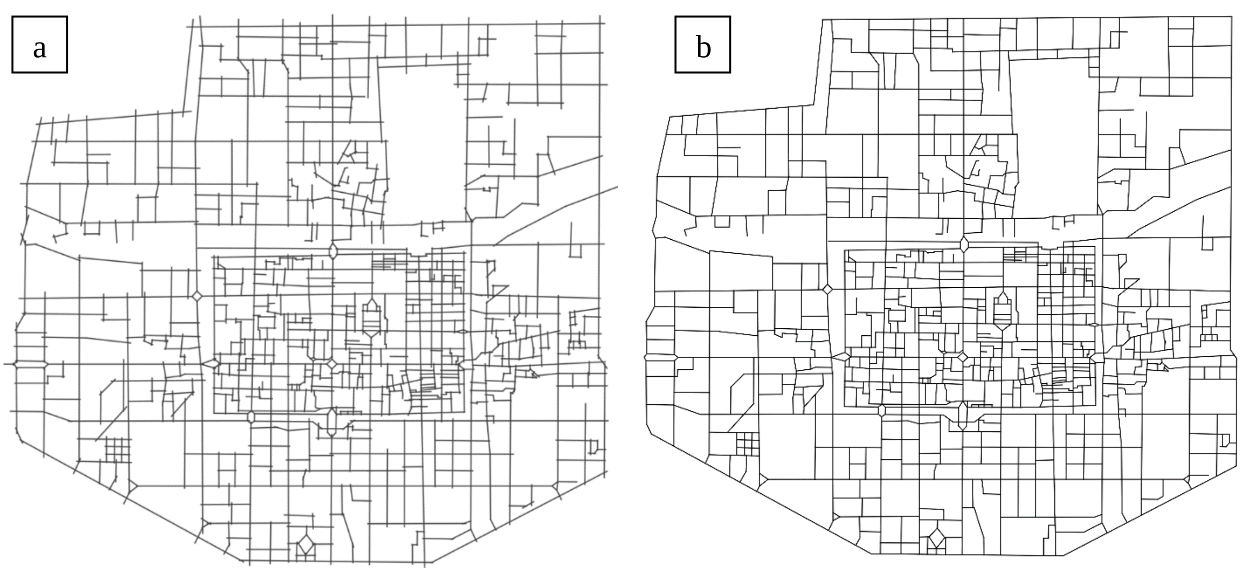


Figure 10 The space syntax model of Xi'an. **a** the axial map. **b** the segment map.

3.5 Multiple Criterion Decision Analysis

Notwithstanding the recent accomplishments in analyzing the human movement in the field of space syntax, limitations still exist. The underlying assumption in the realm of space syntax is that the shape of space and movement is not independent in the city (Hillier, 1997) and the natural movement is determined mainly by the physical form of the urban structure. The notion, in the pursuit of theoretical purity, has neglected the influence of functional magnet such as commercial sites as well as tourist attractions. Monokrousou and Giannopoulou (2016) indicate that in some cases the correlation between integration value and pedestrian movement is not reliable since the study areas incorporate significant function such as commercial use, catering services, and other attractive land use. Also, Mansouri and Ujang (2017) discover that the tourists' movement is more subject to the attractors than the physical configuration of the urban network, and the mixed land use design can facilitate the vitality of the historical street by increasing the density of movement flow. As such, it is essential to introduce a method to quantify the impact of such attractors in the network analysis process of the space syntax. In this thesis, a new research method is proposed to explore the urban form of Xi'an and the human movement pattern in the city with consideration of the combined impacts of both spatial configuration and spatial attractors.

3.5.1 Introduction of MCDA

The MCDA in our research refers explicitly to GIS-based MCDA approaches that emerged in the early 1990s by integrating the GIS and multicriteria decision analysis (Malczewski, 2006). The main steps of MCDA include the following: 1) identifying the problem; 2) listing the criteria (factors); 3) normalization of the factors; 4) determining and assigning the weight; 5) aggregating the criteria; 6) verifying the results. The MCDA has been successfully implemented in supporting the spatial decision-making process for various projects with the ability to evaluate different alternatives that of incommensurate and incompatible criterions, allowing different criteria to have different, user-specified, level of importance (Dragićević, Lai, & Balram, 2015; Rikalovic, Cosic, & Lazarevic, 2014; Sánchez-Lozano, Teruel-Solano, Soto-Elvira, & Socorro García-Cascales, 2013). There are three fundamental elements of MCDA, including decision-makers, criteria, and decision alternatives (Malczewski & Rinner, 2015a). The decision-maker, who is responsible for decision making in the procedures, can be individuals, groups, and even agents (Parker, Manson, Janssen, Hoffmann, & Deadman, 2003b). The criteria in MCDA is often associated with objectives, attributes, and factors, which together constitutes a hierarch hierarchical structure. Saaty (1987) proposed the Analytic Hierarchy Process (AHP) method and the pairwise comparison method to compare as well as assigning weights to different criteria and factors. The method has been proven to be the most popular approaches in GIS-MCDA studies (Malczewski, 2006). The decision alternatives are defined as other options for decision-makers and are either raster or vector data depending on the GIS data models (Malczewski, 1999).

Different from the traditional application of the MCDA in supporting spatial decision-making process where the ultimate aim is to identify the optimal spatial choice or rank different compatible alternatives, this research focuses more on the index values that generated through the MCDA which can be further manipulated through quantitative analysis and data visualization process.

3.5.2 The application of MCDA

3.5.2.1 Problem and the criteria

At the first stage of MCDA, the problem shall be identified by the decision-makers. In this research, the author plays the role of the decision-maker to identify the street segment with the highest human movement density. Subsequently, the criterion that serves as the basis for decision making is selected based on the author's understanding of the problem. For the purpose of quantifying functional attractors, one of the major land-use of the city, residential, is excluded in our study for the following two reasons: 1) residential is not a magnet that targets the whole population but specific residents; 2) The residential area (polygon feature) cannot be accurately represented through POIs (point feature) considering the geographical area it covers.

The criteria of the analysis are built on the classification of the POI data gathered from the Baidu map API. After cleaning and filtering the raw data, there are 10,888 POIs in total. The POIs were reclassified into four relevant categories, including commercial sites (3,125), transportation facilities (406), catering services (6,701), and tourist attractions (656), which are similar to the first-tier classification of the Baidu API (see Table 3). However, the factors of each criterion (shown in Figure 11) are different from the original second-tier classification for the following reasons: 1) the selected factors are the dominant ones in the second-tier regarding the absolute quantity of the POIs, such as those under the catering services and the commerce; 2) the selected factors are most relevant with the characteristics of Xi'an as a historic city, such as the factors under the classification of tourists attraction; 3) the selected factors are in close relation with human activities, such as the factors under the classification of transportation facility.

The primary criterion of the analysis is the NACH value generated by the space syntax analysis, with the consideration that the high NACH could represent high through movement potential of a space (Hillier et al., 2012). The number of POI points within a certain distance (walking distance of 400m) of a street segment serves as another crucial criterion influencing the decision, which helps to quantify the attractors that impact the human movement density in the built environment. The POI points were joined to the street segment in ArcGIS by performing spatial join function according to the above principles. To note, during the joining process, each of the segment was processed separately. Therefore, for instance, for four segments of an intersection, one specific POI data was counted four times independently. Figure 11 shows the framework of the analysis's criteria that is established concerning the POI classification.

3.5.2.2 Normalization

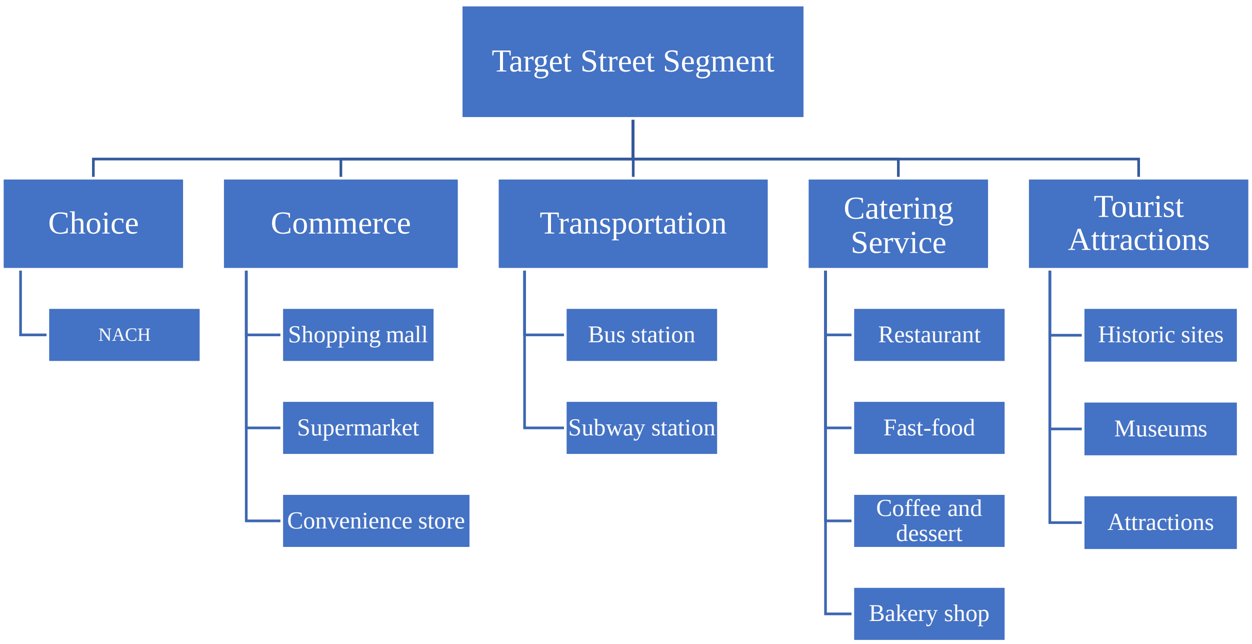


Figure 11 The hierarchy of criteria and factors.

To quantify the criterion or the "functional attractors," the count of POI points of all the segments yielded in the previous stage is normalized to the range from 0 to 1. It is noted that in addition to the three basic elements of the MCDA, the concepts of value scaling, criteria weighting, and combination rules are the primary tools for quantifying the research (Malczewski & Rinner, 2015a). The value scaling or normalization facilitates the transformation of raw data into comparable units for subsequent combination process. The linear form of the global value function (see equation 1) was applied in this research with the consideration of the spatial homogeneity of the research case, where the a_{ik} is the k-th criterion(factor) of the i-th alternative (segment), and the max a_{ik} and min a_{ik} represents the maximum and minimum of the criterion values.

$$v(a_{ik}) = \frac{a_{ik} - min\{a_{ik}\}}{max\{a_{ik}\} - min\{a_{ik}\}} \quad (1)$$

3.5.2.3 Weighting and combination

In this stage, the selected factors are weighted according to the AHP, and the weights and the normalized value of criterion (factor) are combined for each alternative (segment). One of the most widely used methods to determine the weights of the criterion/factors is the aforementioned pairwise comparison (Malczewski, 2006). In general, the method assumes that decision-maker could pairwise compare every two of the n independent alternatives (A1, A2, A3, …, An) according to the Saaty Scale (Saaty, 1989) that rating with values from 1 to 9 (see Table 9).

Table 9 *The preference rating of Saaty Scale*

The description of the importance between two alternatives	Ratings
Equal importance	1
Moderate importance	3
Strong importance	5
Very Strong importance	7
Extreme importance	9
Intermediate value	2,4,6,8

The results can be represented as a reciprocal matrix A = $[a_{ij}]_{nxn}$; a_{ij} is the rating results of the comparison between alternatives A_i and A_j. Table 10 shows the matrix of pairwise comparison among criterion. Using the same pairwise comparison approach, the factors under the same criterion are also weighted (e.g., the shopping mall, the supermarket, and the convenience store under the criteria category of commerce). Table 11 lists the weighting results that are calculated through the pairwise comparison based on our understanding and interpretation of the distinct alternatives as well as factors, and all the weights add up to 1. The Consistency Ratio (CR) is a measurement indicating whether the matrix ratings are randomly calculated, and the CR values under 0.10 are considered to be acceptable (Malczewski & Rinner, 2015b).

Table 10 *The matrix of pairwise comparison among criterion*

Criteria	**Choice**	**Commerce**	**Transportation**	**Catering Service**	**Tourist Attraction**	**Weights**
Choice	1					0.4937
Commerce	1/5	1				0.0902
Transportation	1/5	2	1			0.1189
Catering Service	1/3	3	3	1		0.2227
Tourist Attraction	1/5	1/2	1/2	1/2	1	0.0745

Notes. The number of comparisons is 10, and the Consistency Ratio (CR) is 5.0%

Table 11 *The weights of criteria and factors*

	Weight (%)	Factor	Weight of factor (%)
Choice	49.4	NACH	49.4
Commerce	9	Shopping mall	3.86
		Supermarket	3.86
		Convenience store	1.29
Transportation	11.9	Bus station	8.93
		Subway station	2.98
Catering Service	22.3	Restaurant	6.29
		Fast-food	12.8
		Coffee and dessert	2.05
		Bakery shop	1.16
Tourist Attractions	7.4	Historic site	4.71
		Museum	1.91
		Attractions	0.78

Regarding the combination rules, the Weighted Linear Combination (WLC) was selected to conduct the summation of the weights of the criteria, and the function is as follows:

$$\mathrm{V}\ (A_i) = \sum w_i a_i \tag{2}$$

where V (A_i) is the total value of the ith alternative (the ratings of the segment in terms of their potential human movement density); the w_i is the weights of the ith factor (as calculated and displayed in Table 11); the a_i is the value of the ith factor (refer to Malczewski & Rinner, 2015, pp. 81–82), which in this research, is the count of POIs for each segment as well as the NACH value after normalization. The combination process was conducted in the QGIS through the VectorMCDA plugin, and the results will be introduced and interpreted in the next chapter.

Chapter 4: Findings and Discussions

4.1 General urban form of Xi'an

In this chapter, the general urban form of Xi'an is examined from different perspectives, including the density visualization of the POIs, the conventional space syntax analysis, and the proposed MCDA method.

4.1.1 Kernel density estimation of POIs

The kernel density estimation has been proven to be an effective way to visualize and express the distribution pattern of spatial features compared to Quadrat analysis and Voronoi-based analysis since it considers decay impacts defined by Tobler's first law of geography (Yu & Ai, 2015). To examine the spatial structure of Xi'an based on the POIs, the kernel density analysis was performed in the ArcGIS platform. For the purpose of generating a smooth pattern of the estimation, the parameters of cell_size and search_radius are tested for several times with three options (5 m, 10m, 20m) for the former and five options (400m, 600m, 800m, 1000m, 1200m) for the latter. After the test, the cell size of the function is set to 10 meters, and the serach_radius is set to 600 meters. As shown in Figure 12, there are three notable spatial patterns displayed: 1) the diffusion with no significant cores; 2) dispersed clusters; and 3) linear pattern. The deep colour in the graphs represents the high potential density of the specified factors, indicating the core of the city. Based on the three classifications of the spatial pattern, these estimation graphs are further interpreted.

The only linear pattern is seen in the graph of the subway station. The linear pattern coincides with the existing metro lines of Xi'an: the vertical line in the middle represents Line 2, the vertical line in the right represents the Line 3, and the horizontal line represents the Line 1. The dispersed clustered pattern is demonstrated in graphs including the attractions, the historic site, the museum, the bakery shop, the coffee and dessert shop, as well as the shopping mall. The distribution pattern signifies that these factors tend to congregate in spatial cores of the city with the relatively small amounts of the POIs. As mentioned, the POIs of historic sites, museums and attractions belong to the criteria of tourist attractions, and they share a similar pattern due to their similarity in land use function. Take the graph of the historic site, for example, the large cluster in the upper part represents the national heritage site of Daming Palace and the associated site park. The two clusters in the middle represent the aforementioned Beiyuanmen and Shuyuanmen districts. These clusters could be a key indicator of interpreting the spatial structure of Xi'an from the perspective of tourist attractions. The diffusion pattern is presented primarily by the factors that are visible prevalent in the city, namely the bus station, the restaurant, the convenience store, and the supermarket. The collective features of these patterns are the dark cluster in the upper right part, which represents areas in the vicinity of the aforementioned Jiefanglu district. Also, these factors are an essential part of people's daily life and could potentially indicate human activities in the city.

The spatial structure presented by the kernel density estimation highlights the attractor's role in shaping the urban structure and impacting social activities. Although the density estimation could depict the spatial-temporal form of the city, the results are volatile and tenporary, considering the rapid ongoing transformation of contemporary society. Therefore, it is critical to examine one of the most enduring aspects of the city - the street (J. W. Whitehand, 2001) - to understand its deep structure.

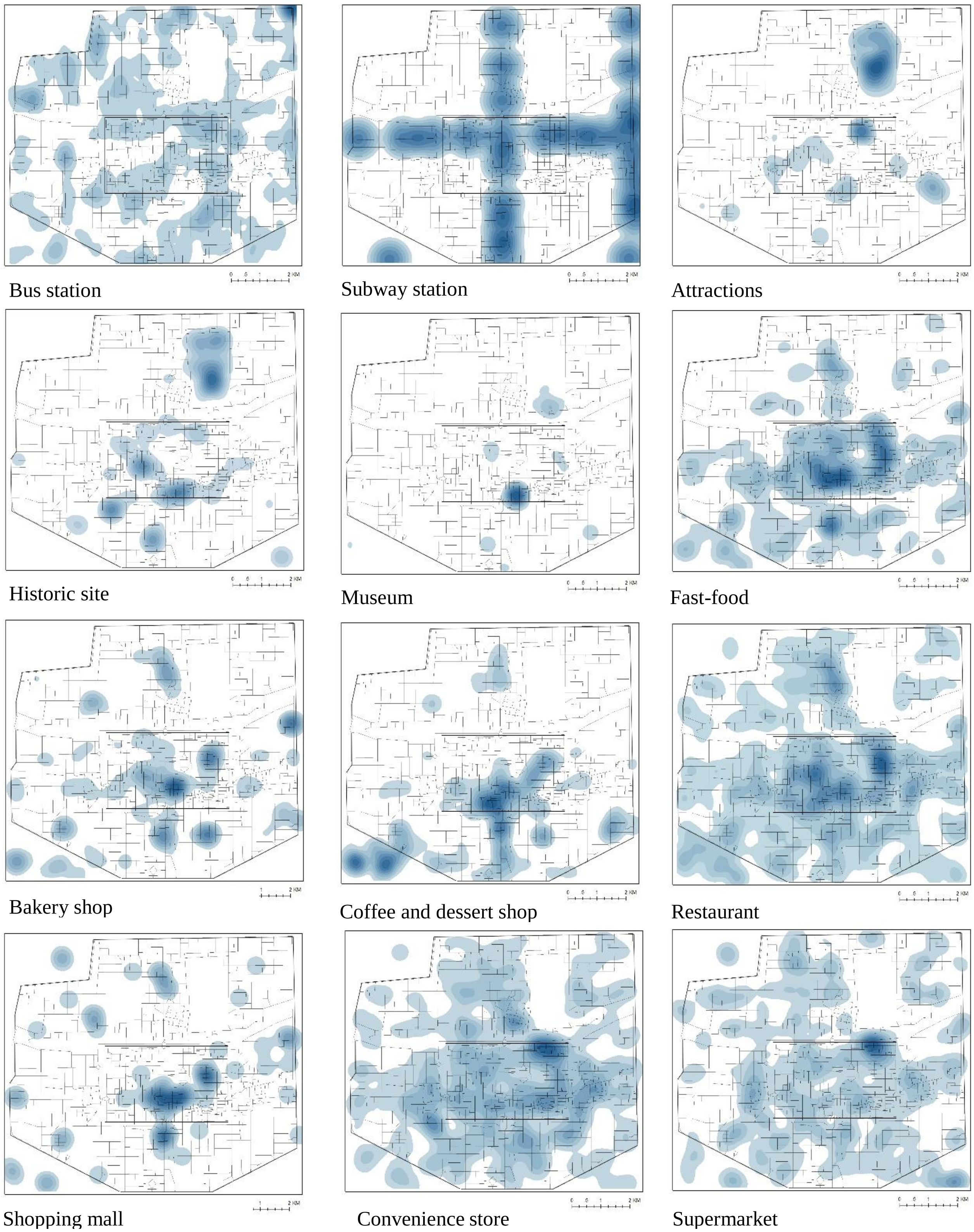


Figure 12 The kernel density estimation of POIs in the city of Xi’an

4.1.2 Spatial configuration

The street, or the abstraction of the street network, is the main research object of the field of space syntax to capture urban's operation law. The city of Xi'an is explored through two of the primary indicators of the space syntax analysis, namely the normalized angular integration (NAIN) and the normalized least angular choice (NACH), both of which have been applied and validated in Hillier's work (2012). As a convention, the red-blue contrast colour range is used as the symbology of the space syntax analysis result, where the red indicates the high value and the blue represents the low value.

Figure 13 shows the general spatial structure of Xi'an based on the NAIN and NACH results that are derived from the space syntax segment analysis. As mentioned before, the integration value is a valid parameter in predicting "to-movement" of the urban area, and the choice value is effective in estimating "through-movement." The left graph reveals the potential destinations (the six apparent red-lines) for Xi'an's citizens. The two horizontal lines represent the two primary roads that connect the east and west part of Xi'an, namely the Beidajie to the north and the Youyi Road to the south. The vertical line in the middle is the most bustling street in Xi'an since the train station locates at the north end of it. While the pattern generalizes the core-streets of Xi'an, it fails to correctly depict the function of the existing axis of Xi'an in the middle of this graph. This may due to the roundabouts situated on the axis disconnect the continuity of the line, causing sharp angular changes that mislead the calculation of the analysis. As for the NACH graph (right), it is still the long red lines that dominate the spatial structure of Xi'an. Compared with the graph of NAIN, a red line appears in the middle of the NACH figure, implying the axis of the city. However, this line transverses only the north area of the city and is interrupted in the middle of the city (the Bell tower). At first glance, both graphs provide a neat hierarchy of the street networks that measured by the colour range. However, the spatial configuration based on the topological relationships between street segments cannot solely demonstrate a comprehensive spatial structure of the urban area.

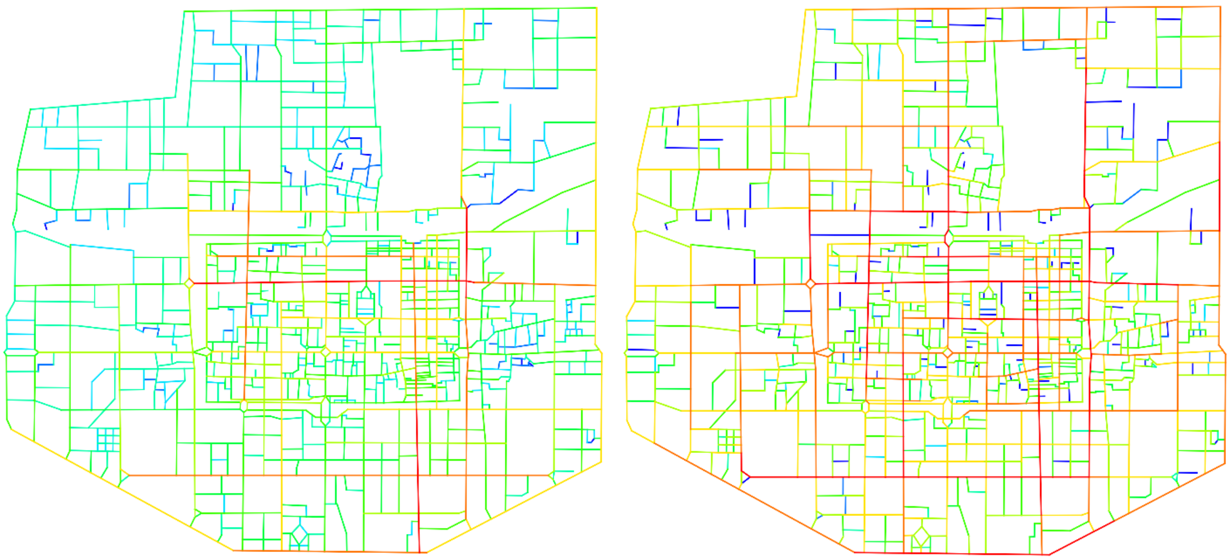


Figure 13 The spatial structure based on the NAIN (left) and NACH (right)

4.1.3 The integrated urban structure

After performing the MCDA in QGIS, an integrated urban structure is constructed. As mentioned before, the rank of the different segments is not the foci of this research. Therefore, in addition to those segments with relatively high values, segments of the whole model are included in the discussion and the visualization to demonstrate a comprehensive urban form of the city. To maintain consistency, the graph is presented through the same symbology used in the space syntax analysis. As shown in Figure14, the long red lines disappear and are displaced by relatively short red lines congregating into clusters, which resembles the distribution pattern of POIs to a certain extent. The interpretations of this integrated diagram are as follows:

1) The city of Xi'an demonstrates a dual-core urban structure, with one located in the existing city core (the Bell Tower) and the other one clustered in adjacent to the

intersection of two long red lines, the Beidajie and the Jiefanglu (two of the busiest roads in the city).

2) There are less red long lines and short blue lines in the graph compared with the NACH analysis, which showcases a heterogeneous urban network where different segments vary in their idiosyncratic characteristics considering the multivariate factors.

3) The majority of red lines are bounded by Xi'an's first ring (the Ming City Wall), which indicates the old downtown area was not abandoned during the urban expansion and sprawl process but been reinforced and rejuvenated and remained as the destination for local citizens.

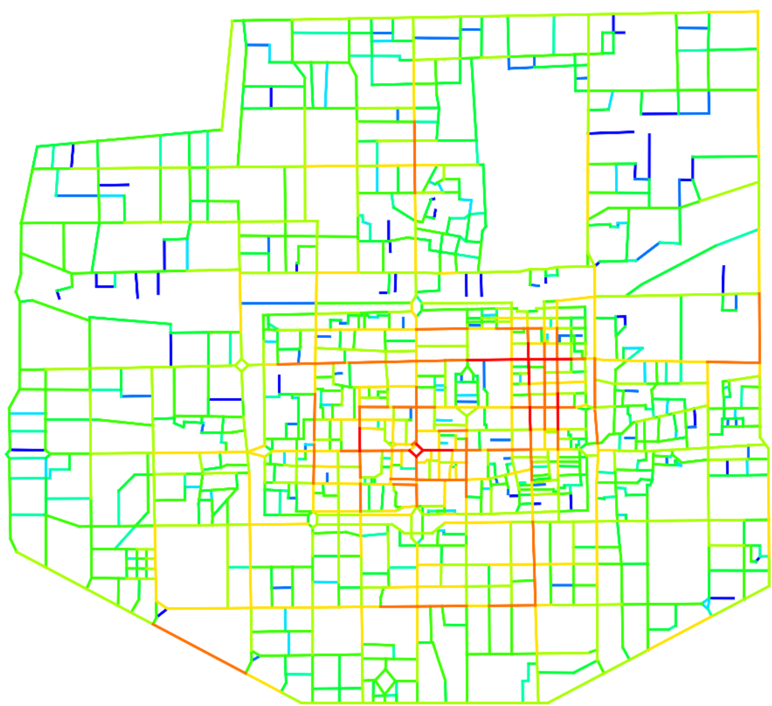


Figure 14 The integrated urban structure of Xi'an based on MCDA

With the application of MCDA, it is feasible and applicable to bridge the spatial configuration of the urban network (deemed as the inner gene of a city) with the daily urban activities (the external expression of a city) to systematically understand the urban form of a city.

However, the reliability of this method needs further verification via quantitative analysis. The following section will examine the different analysis results as well as the observation data of the five selected districts.

4.2 The urban structure at the district scale

4.2.1 The global scale

The observation data was gathered for a total number of 37 gates dispersed in the five selected districts. Before delving into each specific district, it would be of significant importance to initially quantitatively examine the previous analysis results and its relationship with the observation data. As shown in Figure 15a, the values range from 38 to 1194, and the mean is 272.78. Of all the 37 values, 2 of them are outliers that are much larger than the others, and one of them is the outlier that is slightly larger than others. These three values are associated with segments that all located in the Beiyuanmen district as displayed near the center of Figure 15b. It is expected that these outliers will severely impact the correlation analysis of the Beiyuanmen district.

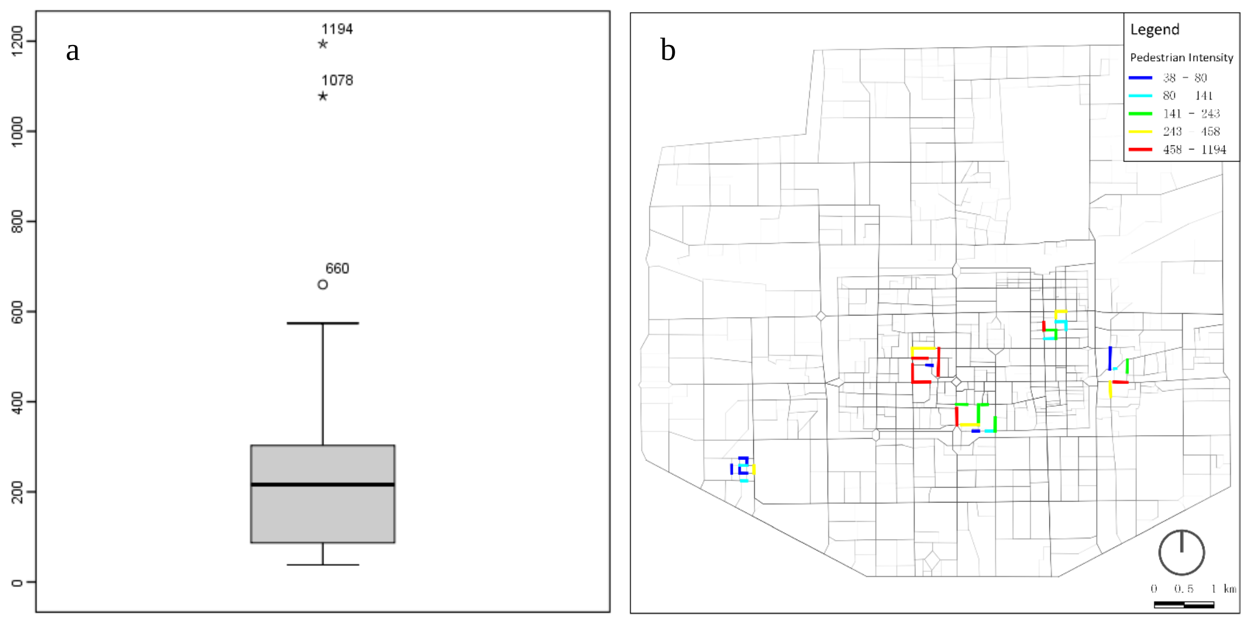


Figure 15 The observed pedestrian intensity of the five districts. **a** the boxplot of the observed data. **b** the map illustrating the pedestrian intensity of the selected districts.

In the previous section, the NACH and NAIN are calculated at a global scale (the radius of n). Here, the NACH and NAIN at both global and local scale (radius of 400m, 800m, 1200m) are to be included in the correlation analysis. Table 12 shows Pearson's correlation among the pedestrian intensity and the analysis results from MCDA as well as space syntax at the global scale. According to the value of the correlation, the pedestrian intensity has a moderate positive relationship with MCDA result with the r at 0.355 and moderate positive relationship with NAIN value with the r at 0.331. Interestingly, Pearson's r between pedestrian and NACH is 0.240, indicating no significant correlation between the two. As mentioned before, the NACH should be a more useful indicator than the NAIN in predicting the human movement volume in the urban area, while the findings here refute the statement. Furthermore, the MCDA result denotes a stronger correlation with Integration values at a different radius than the Choice values. This finding is unexpected since the NACH is one of the criteria in the MCDA process, while the NAIN is not. Therefore, this finding will be further examined and verified in the cases of the five selected districts.

Table 13 lists the correlations among pedestrian intensity and other factors of the "attractors." It appears that the pedestrian intensity has no significant correlation with the majority of these factors except for the "subway" and the "fast-food," both of which are in a moderate negative relationship with the pedestrian. Other intriguing findings are that the factors under same criteria demonstrate a relatively strong correlation among them, specifically the criteria of tourist attraction (the historic sites, attractions, and museums) and the catering service (restaurant, fast-food, and bakery). This phenomenon suggests that factors with similar land use are likely to cluster together spatially, thereby influencing the urban structure through human activities.

The investigation at a global scale helps to reveal the big picture of characteristics of the selected districts, and further exploration will be carried out in the next section to focus on determining the effectiveness of these methods in the local contextual settings.

Table 12 *Correlations among pedestrian intensity and MCDA and Space Syntax analysis results at global scale*

Variables	Pedestrian	MCDA	NACH	NACHr1200m	NACHr400m	NACHr800m	NAIN	NAINr1200m	NAINr400m	NAINr800m
Pedestrian	-	.355*	.240	.208	-.346*	-.029	.331*	.012	-.182	-.217
MCDA		-	.817**	.585**	-.225	.284	.925**	.675**	.416*	.517**
NACH			-	.718**	-.004	.456**	.870**	.655**	.608**	.601**
NACHr1200m				-	.170	.789**	.551**	.630**	.655**	.588**
NACHr400m					-	.533**	-.247	.246	.267	.347*
NACHr800m						-	.282	.569**	.588**	.645**
NAIN							-	.585**	.357*	.448**
NAINr1200m								-	.539**	.924**
NAINr400m									-	.686**
NAINr800m										-

Notes. *. Correlation is significant at the 0.05 level (2-tailed). **. Correlation is significant at the 0.01 level (2-tailed).

Table 13 *Correlations among pedestrian intensity and normalized factors*

Variables	Pedestrian	Nbus	Nsubway	Nsupermark	Nattractio	Nsite	Nmuseum	Nbakery	Ncoffee	Nfastfood	Nrestauran	Ncstore	Nmall
Pedestrian	-	.126	-.345*	-.260	-.122	.100	-.203	.106	.103	.368*	.300	.190	.283
Nbus		-	-.400*	.136	-.405*	-.224	-.071	.391*	.537**	.496**	.322	.287	.449**
Nsubway			-	.253	.116	-.305	-.200	-.311	-.358*	-.543**	-.702**	-.605**	-.402*
Nsupermark				-	-.309	-.541**	-.312	-.096	-.197	-.152	-.158	.180	-.275
Nattractio					-	.659**	.743**	-.451**	-.066	-.557**	-.414*	-.317	-.346*
Nsite						-	.667**	-.163	.067	-.077	-.018	.024	-.093
Nmuseum							-	-.253	.266	-.365*	-.266	-.066	-.168
Nbakery								-	.443**	.851**	.728**	.213	.859**
Ncoffee									-	.365*	.233	.194	.576**
Nfastfood										-	.866**	.409*	.797**
Nrestauran											-	.581**	.637**
Ncstore												-	.068
Nmall													-

Notes. *. Correlation is significant at the 0.05 level (2-tailed). **. Correlation is significant at the 0.01 level (2-tailed).

4.2.2 Jiefanglu district

As mentioned before, the Jiefanglu Commercial District is now Xi'an's iconic commercial district with several commercial complexes, shopping malls, and department stores in the vicinity. As shown in Figure 16, the streets of this area are equipped with high-quality walking space intended for consumers to move from one shopping spot to another. According to the observation data, the highest pedestrian density value of this area is 530, and the lowest is 83, with the mean value of 230.6. As for the NACH (radius n), the maximum is 1.502, and the minimum is 0.856, with a mean of 1.18 (global 0.96). Besides, the MACD analysis values range from 0.51 to 0.72, with a mean of 0.60 (global 0.41).

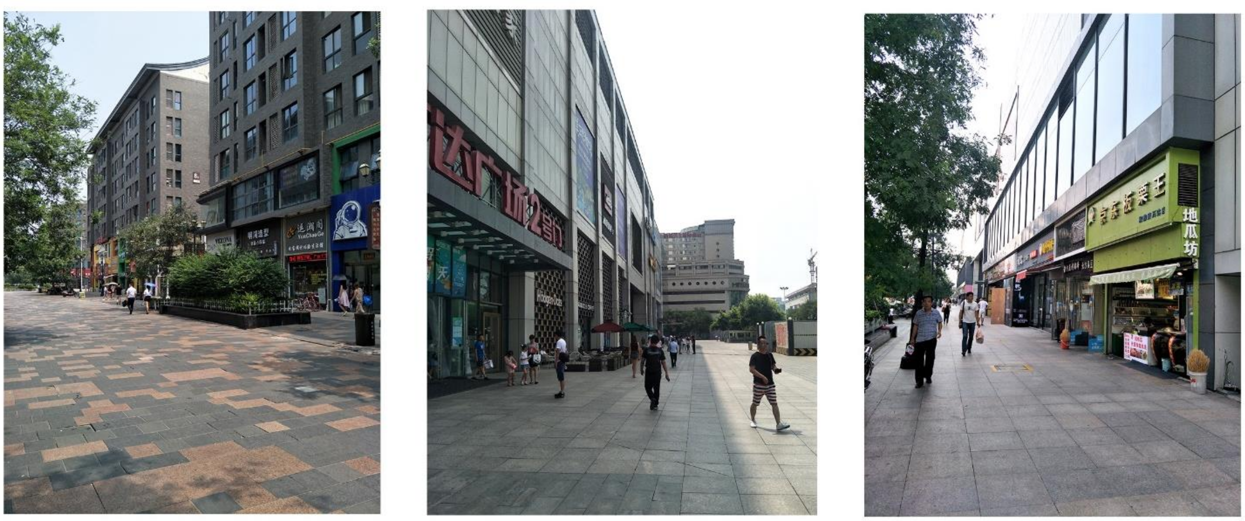


Figure 16 The streets of the Jiefanglu commercial district

Table 14 shows the mean of all the normalized factors' value except for the NACH of Jiefanglu district and that of all the segments of Xi'an as well as their comparison. The objective of exploring this is to identify the dominant factors that could symbolize the predominant function of the district. The mean of the normalized factors at the global and local scale are calculated separately, which are compared later. The comparison ratio measures the concentration of the specific factor. The ratio (local/global) higher than 1 indicates that the specific factor is more concentrated in the area than other areas in the city, while ratio lower than 1 indicates that the factor is less prevalent in the area comparing the whole city. It can be inferred from the table that the main land-use functions of the district include the shopping mall (5.19), bakery shops (4.13), and coffee and dessert shops (3.20), which justifies the local land-use.

Table 14 *The mean comparison of Jiefanglu district*

Factor	Global_Mean	Local_Mean	Comparison
Nbus	0.200338	0.266667	1.33
Nsubway	0.308435	0.099676	0.32
Nsupermark	0.212496	0.294872	1.39
Nattraction	0.112573	0.117647	1.05
Nsite	0.094883	0	0
Nmuseum	0.043677	0.086538	1.98
Nbakery	0.141777	0.585714	4.13
Ncoffee	0.120695	0.386904	3.21
Nfastfood	0.233959	0.673508	2.88
Nrestaurant	0.299582	0.829023	2.77
Ncstore	0.28779	0.431548	1.50
Nmall	0.085588	0.444445	5.19

Notes. The Comparison is calculated by Local_Mean/Global_Mean

In addition to the delineation of land-use, it is also crucial to investigate whether space syntax and MCDA methods can accurately describe and predict the human activities specifically the pedestrian movement on the local scale. Table 15 displays the Pearson's correlation among pedestrian and indicators from both analytical methods. Regrettably, the correlations between pedestrian and MCDA as well as NACH demonstrate no statistically significance at the 0.05 level. On the flip side, there is a strong correlation between pedestrian and NACHr400m (0.876) as well as NACHr800m (0.801). Hence the local NACH value is the most effective indicator regarding Jiefanglu district. While the MCDA has a strong correlation with Integration values on the global scale, here in the Jiefanglu district, the Integration values and Choice values have a similar correlation with the MCDA.

Table 15 *Correlations among pedestrian intensity and MCDA and Space Syntax analysis results of Jiefanglu District*

Variables	Pedestrian	MCDA	NACH	NACHr1200m	NACHr400m	NACHr800m	NAIN	NAINr1200m	NAINr400m	NAINr800m
Pedestrian	-	.662	.697	.661	.876**	.801*	.684	.660	.651	.694
MCDA		-	.993**	.847**	.358	.539	.979**	.848**	.573	.668
NACH			-	.861**	.428	.603	.985**	.881**	.632	.741*
NACHr1200m				-	.376	.784*	.800*	.935**	.714*	.846**
NACHr400m					-	.674	.416	.495	.533	.596
NACHr800m						-	.546	.714*	.823*	.887**
NAIN							-	.817*	.532	.705
NAINr1200m								-	.760*	.878**
NAINr400m									-	.809*
NAINr800m										-

Notes. *. Correlation is significant at the 0.05 level (2-tailed). **. Correlation is significant at the 0.01 level (2-tailed).

4.2.3 Shuyuanmen district

The Shuyuanmen historic district is anchored with cultural sites and gradually transformed into a tourist attraction for visitors who are interested in Chinese art and literature in recent years. The motor vehicles are prohibited inside the Shuyuanmen district, so some of the selected streets are pedestrian-oriented with alternative transportation approaches such as cycles and scooters (see Figure 17). The maximum pedestrian density in this area is 574, and the minimum is 64. The mean is slightly lower than Jiefanglu district at 222.25. In terms of the NACH (radius n), the highest value is 1.219, and the lowest is 0.837. The mean of NACH is also moderately lower than that of Jiefanglu district at 1.10. The MCDA values range from 0.46 to 0.63, with the mean at 0.54.

Figure 17 The streets in the Shuyuanmen historic district

As shown in Table 16, the mean value of the normalized museum is 17.6 times than that of the global mean, indicating the museum is a significant attractor in this district. Other factors such as historic site (7.36) and tourist attraction (3.59) stand out from the rest, representing the primary land-use function of the district.

Table 16 *The mean comparison of Shuyuanmen district*

Factor	Global_Mean	Local_Mean	Comparison
Nbus	0.200338	0.1583333	0.79
Nsubway	0.308435	0.19538425	0.63
Nsupermark	0.212496	0.21153825	1
Nattraction	0.112573	0.404411875	3.59
Nsite	0.094883	0.698529375	7.36
Nmuseum	0.043677	0.76923075	17.61
Nbakery	0.141777	0.325000163	2.29
Ncoffee	0.120695	0.452381	3.75
Nfastfood	0.233959	0.358209075	1.53
Nrestaurant	0.299582	0.5007185	1.67
Ncstore	0.28779	0.360119	1.25
Nmall	0.085588	0.23611113	2.76

Notes. The Comparison is calculated by Local_Mean/Global_Mean

According to Pearson's correlation analysis, the pedestrian intensity has no statistically significant correlation with the listed indicators in Shuyuanmen district. The highest Pearson's r is seen in the correlation between pedestrian with the MCDA at 0.411, whereas the lowest pertains to the NACH (0.063). Regarding the correlation between MCDA and other indicators, there is a statistically significant positive correlation between MCDA and NACHr1200m at 0.923 and between MCDA and NAINr1200m at 0.790. As investigated by Mansouri and Ujang (2017), the large volume of tourists may contribute to the uncertainty and randomness regarding predicting the pedestrian intensity. This phenomenon is more evident in the following case, the Beiyuanmen district.

Table 17 *Correlations among pedestrian intensity and MCDA and Space Syntax analysis results of Shuyuanmen district*

Variables	Pedestrian	MCDA	NACH	NACHr1200m	NACHr400m	NACHr800m	NAIN	NAINr1200m	NAINr400m	NAINr800m
Pedestrian	-	.411	.063	.264	-.550	-.523	.178	.233	.388	-.138
MCDA		-	.313	.923**	.106	.264	.257	.790*	.654	.592
NACH			-	.572	.547	.304	.975**	.614	.743*	.553
NACHr1200m				-	.382	.509	.493	.859**	.790*	.724*
NACHr400m					-	.800*	.484	.373	.394	.628
NACHr800m						-	.150	.455	.388	.721*
NAIN							-	.544	.693	.434
NAINr1200m								-	.738*	.900**
NAINr400m									-	. .664
NAINr800m										-

Notes. *. Correlation is significant at the 0.05 level (2-tailed). **. Correlation is significant at the 0.01 level (2-tailed).

4.2.4 Beiyuanmen district

The Beiyuanmen Muslim district, also known as the Muslim Quarter, maybe the most famous tourist's destinations in Xi'an. Although the motor vehicles are not officially banned here, the crowded streets prevent drivers from passing through, thereby making the majority of streets in this district pedestrian-oriented. Figure 18 depicts the general streetscape of the districts with stalls and shops alongside the street. With the large volume of tourists, the pedestrian density is notably higher than the other two districts. The highest observed value is 1194, and the lowest is 38, with a mean at 560.5. With regards to the NACH, the maximum, minimum, and mean are 1.344, 0.777, and 1.134 respectively. Concerning the MCDA values, it has the highest mean at 0.55 among all the selected cases.

Figure 18 The streets in the Beiyuanmen Muslim district

According to Table 18, the factor of historic site ranks the first in the comparison, suggesting the place's role as a historic neighbourhood. The fact that the factor of the shopping mall is the second highest factor is surprising since there is no type of land-use function based on our in-site observation. Nevertheless, there are some shopping malls at the periphery of the area that could impact the results. The expected function that could symbolize the characteristics of the district such as fast-food and restaurant have only the relatively high value of comparison, 2.75 and 2.51 respectively. While the Beiyuanmen district is widely known as the food and snack street area with diverse restaurants and food stalls, other underlying factors could also attract people to the place.

Table 18 *The mean comparison of Beiyuanmen district*

Factor	Global_Mean	Local_Mean	Comparison
Nbus	0.200338	0.116667	0.58
Nsubway	0.308435	0.182230	0.59
Nsupermark	0.212496	0.198718	0.94
Nattraction	0.112573	0.242647	2.16
Nsite	0.094883	0.544118	5.73
Nmuseum	0.043677	0.048077	1.10
Nbakery	0.141777	0.457143	3.22
Ncoffee	0.120695	0.190476	1.58
Nfastfood	0.233959	0.643657	2.75
Nrestaurant	0.299582	0.752874	2.51
Ncstore	0.28779	0.352678	1.23
Nmall	0.085588	0.361111	4.22

Notes. The Comparison is calculated by Local_Mean/Global_Mean

Concerning the correlation among pedestrian intensity and the analysis results, no significant correlation is established, and the majority of the Pearson's r values are negative. As mentioned earlier, there are three outliers of the pedestrian intensity that may occur due to the massive volume of unpredicted tourists in this district, which could cause the situation. As for the correlation among MCDA and other indicators, it is apparent that the MCDA showcases a stronger correlation with Integration than the Choice, which is similar to the findings on the global scale.

Table 19 *Correlations among pedestrian intensity and MCDA and Space Syntax analysis results of Beiyuanmen District*

Variables	Pedestrian	MCDA	NACH	NACHr1200m	NACHr400m	NACHr800m	NAIN	NAINr1200m	NAINr400m	NAINr800m
Pedestrian	-	-.273	-.208	.157	-.041	.142	-.339	-.011	-.350	-.296
MCDA		-	.906**	.526	-.544	.114	.957**	.861**	.782*	.887**
NACH			-	.660	-.260	.418	.935**	.898**	.842**	.950**
NACHr1200m				-	.180	.845**	.440	.857**	.761*	.778*
NACHr400m					-	.584	-.452	-.221	.015	-.150
NACHr800m						-	.126	.538	.506	.512
NAIN							-	.814*	.733*	.858**
NAINr1200m								-	.848**	.928**
NAINr400m									-	.953**
NAINr800m										-

Notes. *. Correlation is significant at the 0.05 level (2-tailed). **. Correlation is significant at the 0.01 level (2-tailed).

4.2.5 Tang West Market district

The Tang west market district, also known as Datang Xishi cultural, scenic region, is built on the archaeological site of the west market of the Tang dynasty. As can be seen from Figure 19, the streets inside the district are pedestrian-oriented, and motor vehicles are strictly prohibited. During the first two observation periods (11:00-12:00 and 15:00 to 16:00), only a few pedestrians appeared in the district. It was not until the last observation period that crowds entered the districts, and large numbers of pedestrian intensity were noted. Therefore, the pedestrian intensity is the lowest among the five districts with a minimum of 40, a maximum of 338, and a mean of 109.38. Similar to the pedestrian intensity, the NACH and MCDA values of the district is also the lowest, with mean at 0.98 and 0.45 respectively. Since the Tang west market district is outside Xi'an's 1st ring and close to the 2nd ring, such results are expected.

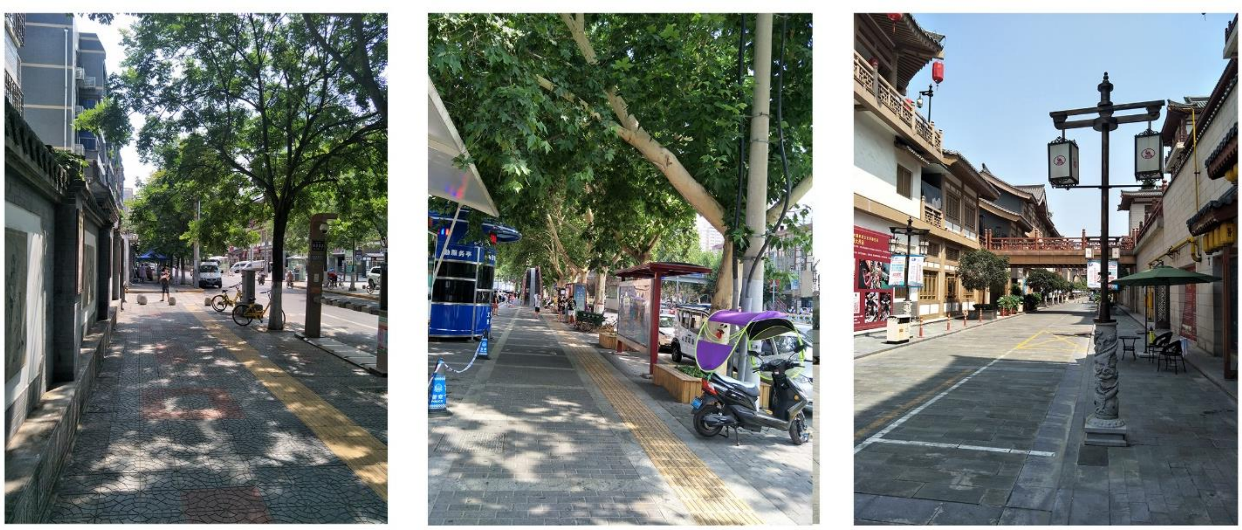


Figure 19 The streets in the Tang west market district

With regards to the representative characteristics of the district, the shopping mall (2.60), bakery (2.54) and tourist attraction (2.35) are among the highest values of comparison. Apart from the factor of attraction, the factors of shopping mall and bakery are both significant in the four districts above. By reviewing Table 13, it is notably that there is a strong correlation between the two factors with Pearson's r at 0.859. Another noteworthy thing is that the factor of the convenience store has the lowest value of comparison at 0.53, inferring the lack of inter-neighbourhood interactions and residential quarters in the district.

Table 20 *The mean comparison of Tang West Market district*

Factor	Global_Mean	Local_Mean	Comparison
Nbus	0.200338	0.125000	0.62
Nsubway	0.308435	0.566666	1.84
Nsupermark	0.212496	0.304487	1.43
Nattraction	0.112573	0.264706	2.35
Nsite	0.094883	0.058824	0.62
Nmuseum	0.043677	0.076923	1.76
Nbakery	0.141777	0.360715	2.54
Ncoffee	0.120695	0.232143	1.92
Nfastfood	0.233959	0.304105	1.30
Nrestaurant	0.299582	0.355603	1.19
Ncstore	0.28779	0.151786	0.53
Nmall	0.085588	0.222222	2.60

Notes. The Comparison is calculated by Local_Mean/Global_Mean

Regarding the correlation between pedestrian intensity and analysis results, both NACH and MCDA show a strong positive correlation with the pedestrian. However, the NAIN again outweighs the other indicators with the highest r at 0.903. Besides, the MCDA also have a stronger correlation with Integration indicators than the Choice indicators. In a nutshell, the MCDA and space syntax methods are both effective in predicting pedestrian movement in the district. While considered as a tourist attraction with diverse land uses, the Xishi district is not impacted by the movement flow attributed to the tourists that deemed as a primary factor in distorting the prediction of both methods.

Table 21 *Correlations among pedestrian intensity and MCDA and Space Syntax analysis results of Xishi District*

Variables	Pedestrian	MCDA	NACH	NACHr1200m	NACHr400m	NACHr800m	NAIN	NAINr1200m	NAINr400m	NAINr800m
Pedestrian	-	.854**	.863**	.609	-.179	.370	.903**	.768*	.387	.712*
MCDA		-	.989**	.761*	-.028	.452	.974**	.900**	.548	.767*
NACH			-	.818*	.045	.529	.964**	.904**	.582	.788*
NACHr1200m				-	.528	.865**	.723*	.890**	.863**	.874**
NACHr400m					-	.648	.008	.134	.410	.156
NACHr800m						-	.429	.662	.860**	.745*
NAIN							-	.841**	.450	.701
NAINr1200m								-	.836**	.961**
NAINr400m									-	.914**
NAINr800m										-

Notes. *. Correlation is significant at the 0.05 level (2-tailed). **. Correlation is significant at the 0.01 level (2-tailed).

4.2.6 Dongguan district

The Dongguan district is distinctive to the other cases since the predominant land-use of this area is residential. Hence the resident's interaction and social activities are the main factors impacting the pedestrian movement pattern. As depicted in Figure 20, the streets in the district hosts mixed-transportation system and the walkways are in poor conditions where the unregulated parking motor vehicles frequently occupied the space. In terms of the observed pedestrian intensity, the value ranges from 76 to 488 with the mean of 222.2, which is at the same level as the Jiefanglu district and the Shuyuanmen district. Meanwhile, the mean of NACH (radius n) and MCDA are 1.03 and 0.44 respectively, which are very close to the global mean.

Figure 20 The streets in the Dongguan district

Therefore, the district is the most representative case of the general situations of the streets in Xi'an. In addition to the three parameters, the findings revealed from Table 22 also justify the assertion. According to Table 22, none of the comparison values is higher than 2 with the highest at 1.99 (tourist attraction), and no factor outweighs others significantly. With no dominant characteristics, the district presents the authenticity of the daily street life of Xi'an.

Table 22 *The mean comparison of Dongguan district*

Factor	Global_Mean	Local_Mean	Comparison
Nbus	0.200338	0.093333	0.47
Nsubway	0.308435	0.339916	1.10
Nsupermark	0.212496	0.343589	1.62
Nattraction	0.112573	0.223529	1.99
Nsite	0.094883	0.117647	1.24
Nmuseum	0.043677	0.030769	0.70
Nbakery	0.141777	0.160000	1.13
Ncoffee	0.120695	0.152381	1.26
Nfastfood	0.233959	0.235821	1.01
Nrestaurant	0.299582	0.441379	1.47
Ncstore	0.28779	0.473810	1.65
Nmall	0.085588	0	0

Notes. The Comparison is calculated by Local_Mean/Global_Mean

As listed in Table 23, Pearson's r between pedestrian intensity and MCDA is 0.911, and the correlation is significant at 0.05 level. While the r between pedestrian and NACH is 0.839, the correlation is not statistically significant. Considering the correlation between MCDA and space syntax indicators, no statistical significance is shown. Nevertheless, there is a slight difference in terms of r. The MCDA has a higher r with Choice at the radius of 1200m and has a higher r with Integration at the radius of 400m and 800m. Similar to the findings in section 4.2.1, the pedestrian intensity has a higher and significant correlation with the MCDA compared with NACH.

Table 23 *Correlations among pedestrian intensity and MCDA and Space Syntax analysis results of Dongguan District*

Variables	Pedestrian	MCDA	NACH	NACHr1200m	NACHr400m	NACHr800m	NAIN	NAINr1200m	NAINr400m	NAINr800m
Pedestrian	-	.911*	.839	.527	.336	.386	.739	.664	.696	.603
MCDA		-	.982**	.797	.417	.595	.763	.684	.878	.659
NACH			-	.854	.529	.701	.674	.729	.931*	.681
NACHr1200m				-	.281	.858	.688	.692	.944*	.788
NACHr400m					-	.512	-.246	.545	.495	.225
NACHr800m						-	.381	.881*	.905*	.875
NAIN							-	.466	.643	.670
NAINr1200m								-	.867	.929*
NAINr400m									-	.864
NAINr800m										-

Notes. *. Correlation is significant at the 0.05 level (2-tailed). **. Correlation is significant at the 0.01 level (2-tailed).

4.3 From qualitative to quantitative urban from

From the inception of urban morphology, the theory has evolved simultaneously with the available "tools" that provided by the advancement of technology, such as the information technology, geographical information science, automation and computation. The motives of the study on the urban form have slightly shifted from "understanding the existing urban form by examining the past" to "predicting the future through the modelling of the present." It is argued by Batty (2018) that the future city is not predictable since the city is a complex, intricate, and indirect organism that grows primarily based on spontaneous bottom-up processes, but is invented by the individuals of the contemporary society. Both the historico-geographical and typological approach falls into the first paradigm of relying on the past (historical maps and building plans) to yield an informative understanding of the continuum of the urban form transformation process, and in turn, explain the rationale of the presence of the existing urban form. Therefore, these two approaches are most conducive in directing urban practices such as urban conservation and regeneration and urban design (Kai & Fei, 2009). In comparison, the spatial analytical approach focuses on the dynamics of the city and embraces the data of the constantly changing present to simulate the urban form. As pointed out by Batty (2018), the notion of "form follows function" is no longer applicable in understanding the urban form of this age, researchers have to capture the "pulse of the city," the flows or the interactions happening in the city, to be prepared for the transformation leading to the future city.

The space syntax approach is situated somewhere between these two paradigms, predicting the human movement that shaping the urban form through relatively static features from the past, "the street network." Building on the theory of natural movement, the space syntax reveals that it is the configuration of the urban network that primarily determines the pedestrian movement patterns, and the attractors only serve as complements or multipliers for the established system (Hillier et al., 1993). Ye and van Nes (2014) argued that while the space syntax approach provides a comprehensive analysis for the street network; it is constrained by the specific morphological aspect hence ignoring the implications of other morphological aspects such as density and land-use diversity. The integration of MCDA and space syntax analysis sheds light on a novel perspective on understanding urban form by highlighting the interplay of street network configuration and the land-use function. The general structures of Xi'an revealed through the three perspectives in section 4.1 contribute to the understanding and interpretation of the inner mechanism of Xi'an from the morphological attitude.

The tradition of applying space syntax analysis in modelling the urban's situation and predicting the human movement has been widely accepted in the field of urban morphological studies. Notwithstanding the quantitative nature of space syntax approach, the colourful pattern displayed on the network map is more straightforward for people to comprehend. The emerging urban data facilitate the paradigm shifts in urban studies from "Planning and Design to Urban Analytics and City Science," (Batty, 2019) and the ability to visualize the numbers through a neat and attractive graph is vital. From the well-designed graph; it is more convenient to identify the morphological features of the urban area, such as the city core, the peripheral regions, and streets with unique characteristics.

The five distinctive study areas each represent a potential magnet that attracts people and generates dense human movement pattern, including commerce, catering, culture, tourism, and daily life. The POIs data serves as the primary indicator in quantifying and delineating the major land-use function of the district, providing insight into the relationship between the functionalized urban form with human movement. Based on the previous results, the indicators generated from space syntax analysis provide a valid prediction of the pedestrian intensity for Jiefanglu, Xishi, and Dongguan district, and the Integration indicators perform better than the Choice indicator in some cases. In comparison, the MCDA generally overperform the space syntax in districts other than the Beiyaunmen district. As specified earlier, the observed pedestrian intensity data of Beiyuanmen district contains three outliers which severely distort the prediction of both methods. Although considered as outliers in the statistics, the observed data is indeed the reflection of the real world. In fact, the abnormal pedestrian intensity is caused by the peculiar land-use function of the district that attracts the unforeseeable volume of people, specifically the tourists. Consequently, for urban areas like Shuyuanmen district and Beiyuanmen district, it is critical to consider factors other than the configuration of the street network that could potentially influence the human movement pattern.

It is noteworthy that the criteria weights for the implementation of MCDA of the five districts are identical, so the spatial heterogeneity is ignored in the analysis process. To achieve a more effective model for understanding the morphological features and predicting human movement pattern in the urban area, targeted design of criteria weights for different districts is essential.

Chapter 5: Conclusions and Recommendations

The unprecedented urbanization process in China has substantial impacts on the urban form as well as the internal spatial structure of cities in China. There are more than 600 cities in China, and around 100 cities have a population larger than 1 million. As the habitat for more than half the population of a Chinese citizen, the urban area is a complex and paramount research object. The burgeoning information technology also contributes to this complexity of cites, shaping the cities technology-driven and hard to plan. On the other hand, the new urban science equips urban researchers with a dynamic lens into the planning of future cities. Meanwhile, the integration of research methods regarding unravelling the puzzle of urban form is imminent. This thesis recaps the research trajectory on the proposition of urban form, bridges the gap between space syntax and spatial analytical methods, and, most importantly, facilitate the understanding of the current urban form of the city of Xi'an.

5.1 Summary of findings

Throughout the research, the research questions proposed in Chapter One are successfully responded. As for the first question, the open datasets that are utilized in this research corresponds to a new paradigm shift in the field or urban studies. Batty (2012) deemed that the rapidly growing new datasets are leading and justifying new theories and the empirical studies on cities, thus becoming "big science" oriented. The OSM and POIs are the two most common forms of open data, but they serve as the most critical roles in the research process: the raw network and the quantitative attractors. With the available open urban datasets, it is expected to witness increasing numbers of studies that embraces this opportunity. A thorough discussion was included in Chapter Three regarding the acquisition, cleaning, manipulation, and management of the datasets.

In terms of the second question, this research adds to the existing literature with a new perspective to integrate the Space Syntax with the MCDA to incorporate both "configuration" and "attractor" in human movement research. With the analytical framework of MCDA, it is possible to quantify and combine the "function" and the "configuration" at an equivalent level. It is noted that the integration also bridges the space syntax approach with the spatial analytical approach in the broad context of the advancement of geographic information science and the update of the work platform and analytical tools. Following the MCDA analysis, the configuration of the urban network can be translated into one of the criteria that support our decision-making process in understanding the urban form and identifying the optimal segments.

The general urban form of Xi'an and the urban morphological characteristics of the five selected districts are presented and examined in Chapter Four, which responses to the third research question. Based on the findings, it is concluded that the City of Xi'an is a monocentric city, and the old city core bounded by the Ming City Wall remains vibrant nowadays. Compared with the conventional space syntax analysis, the proposed method constructs an integrated structure that represents both the configurational and functional characteristics of the city. Additionally, the proposed method could provide more reliable predictions for the pedestrian movement, based on which more urban morphological features pertain to the movement economy can be inferred.

5.2 Research Significance

This research is significant in the following aspects:

1. A new perspective on urban form. The major contribution of this research is to equip urban morphologists and urban researchers with a new perspective on the complex urban form by combining both configurational and functional dimension of cities. In addition, the quantitative interpretation of urban form provides a more detailed and precise way to complement the traditional intuitive perception of the urban composition and inner mechanism.
2. Embracing the new urban data. With the utilization of the new urban data in the form of OSM and POIs, this research demonstrates the opportunity of embracing the new urban data in urban studies and highlights the advantages of the new urban data compared to the conventional datasets, adding to the empirical studies regarding the collection, management, manipulation, as well as interpretation of the new datasets.
3. Advancing the research field of Space Syntax. Traditionally, the primary research object of the Space Syntax is the configurational structure of the city, specifically the street network that shapes the city. However, the functional aspect of the urban space is ignored, which sometimes leads to fallacies in predicting the human activities associated with the urban structure. This research, for the first time, integrates the effect of the "functional attractors" with the forces from geometrical features of the urban form, consolidating the domain of Space Syntax in terms of the comprehensiveness.
4. Quantifying urban form of the city of Xi'an. This research learns from the rising trend of quantitative urban studies, providing an interpretation to the urban form of Xi'an anchored with a quantitative nature. The used and generated datasets in this research

will be open to further researchers who wish to investigate in-depth aspects of the city of Xi'an, for the consideration of promoting quantitative urban studies as well as the spirit of collaboration.

5. Inventing a new research method. The most vital contribution of this research is the proposed new research method that integrates the space syntax analysis with the multi-criterion decision analysis (MCDA) in modelling the urban form. This new method, though is in its infant state in nature, has the potential to systematically and comprehensively simulating the urban structure and the human movement pattern associated with the spatial structure, thereby providing insights into the urban space and the thriving urban life.

5.3 Limitations

There are several limitations of this research, involving with the data collection, the detailed procedures of the application of research methods, and the data analysis process.

As recommended by Grajewski and Vaughan (2001), the number of observation gate should be around 25 or more. In this research, only eight gate positions were set for each district considering the considerable small size of the area. Nevertheless, more gates could provide more concise and consistent data for the correlation analysis, thereby improving the validity of the results. Moreover, the boundary of the selected districts is blurred, and it is hard to assess the impacts of the districts to define the border of the district with objectivity. Therefore, for the consideration of comprehensiveness, it is recommended to gather more gate observation data and make clear and objective delineation of the district coverage for further studies.

Furthermore, the data quality of OSM-China is under debate (Liu & Long, 2016). In this research, the network model is primarily based on city level roads. Therefore, the underlying connections between different roads in the form of unidentified streets or lanes are ignored, which could affect the accuracy of the entire model. Similarly, the data quality of POI data could also be improved. The geotagged POIs are point features that represent the abstraction of the real entity without considering the geometrical characteristics. Therefore, for those POIs that represent a large area, such as the historic sites and the shopping malls, the precision of location information is distorted.

Another limitation is that during the pairwise comparison process, the ratings (weights) for criteria are based primarily on the researcher's understanding of the study area. Although the researchers act as the decision-maker of the analysis, the ratings are, to some extent, subjective. For further improvements, the rating standards could be facilitated by academic literature, expert knowledge, as well as crowdsourced perspectives, and the preference measurement could be enhanced by specifying the confidence interval of the weight. Also, as mentioned in the previous section, it is recommended to construct the rating criterions individually for each selected case to consider spatial heterogeneity in similar future studies. In terms of the value scaling (normalization) stage, the local value function (Malczewski & Rinner, 2015b, p. 34) is another essential approach to take the spatial heterogeneity of preferences into consideration in MCDA, allowing a more fine-grained perspective towards tackling with the spatial choice issues.

It is noteworthy that the issue of the uncertainty associated with the MCDA is not underlined and discussed, which is a significant defect of this research. The uncertainty refers to the situation that with no or not complete information available in the real world, the decision-makers are not able to provide an accurate description of the system (Malczewski & Rinner, 2015b, p. 191). Since the criterion values and criterion weights are the primary sources of the uncertainty, both the direct and indirect methods are commonly applied to examine the effects of the uncertainties in MCDA. It is recommended to conduct a sensitivity analysis (SA) to evaluate how the output of the analysis is affected by the uncertainty associated with the input factors (e.g., the criterion values and weights). The further movement of considering the uncertainties such as fuzzy and lack of information in the proposed research method is an essential step in achieving more comprehensive and robust research outcomes. For instance, when joining POI data to segments, the radius of 400 m is used as the parameter. However, this value is inherited from the conventional Space Syntax analysis, and may not be applicable or valid when performing MCDA. Through the SA, it is possible to examine different radius within a specific range to identify the most appropriate ones. It is paramount for further researchers to carry out SA before applying the method proposed in this research.

Finally, when performing the bivariate correlation, not all of the variables are normally distributed with some of them are skewed distributed. Besides, with the limited number of samples, some of Pearson’s r among the indicators demonstrates no statistically significance, which lessens the reliability of the research findings and conclusions.

5.4 Recommendations

5.4.1 Future research

The research method from this study may be applicable in further urban studies regarding exploring or explaining the human movement pattern as well as the distinctive urban form. The integrated analytical method is conducive in, but not limited to, the following scenarios:

1) Research focusing on identifying the centers or determining the spatial structure of an urban area with consideration of human's activity.
2) Research on simulation and prediction of the traffic volume in urban areas.
3) Research on the location choice of specific land-use function with consideration of underlying popularity.
4) Research on social aspects such as housing affordability, social disparity, public health with regards to their relationship with the spatial distributions.

More importantly, the method contributes to the field of quantitative urban studies by connecting the quantitative analysis of space syntax with spatial analytical methods in the context of burgeoning information communication technology. Moreover, with the increasing availability of urban data generated from smart sensors citywide, this research can be reinforced by more fine-grained spatial and temporal datasets. For instance, the pedestrian intensity data derived from the gate observation can be substituted by real-time traffic volume data gathered by traffic cameras or similar censors. Nevertheless, it is critical to bear in mind that the data can only tell us what is going on but not why is the case. The further research that built on this research should transit from "understanding space" to "shaping place," which is the priority related to the urban planning by focusing on the interaction between human and physical space.

5.4.2 Planning practice

In addition to the advancement in theoretical discussion and research methods, the ultimate goal for this research is to instruct the prospective planning practices. In essence, the planning decisions deal with the issue of how to build harmonious relationships between people and the physical urban environment. Therefore, the priority for urban planners is to comprehensively understand the characteristics of the existing urban structure from both geometric and social dimensions. In traditional planning practices, the land-use is the prerequisite for planning schemes. However, with the increase of land-use diversity in urban areas, the conventional criterion that determines the primary use of a particular district is not applicable anymore. This research proposes a method to quantify the land-use function as well as attractors of a specific land plot in the city, which is conducive to quantitative evaluation of land-use function in the planning process, offering planning decision-makers with tools to both predict and evaluate the planning scenarios. Oftentimes, the planning proposals involve the change of urban structure (road network) and the adaptation of land-use. Based on this research, it is noted that the alteration of these two aspects of the urban area will severely impact the urban form and the human movement pattern associated, which can be a vital aspect in evaluating the proposed planning schemes. By implementing the modelling method proposed in this research, it is possible to add value to planning processes by integrating science-based and human-centred analysis. Besides, the visualization of the analysis result (colorful pattern) can facilitate communications between planners and stakeholders.

Thanks to the new urban data, the dynamic nature of the urban transformation has been recorded in a traceable format, such as the POIs. The dynamic data, combined with the most durable structure of the urban system – the street network – provides urban planners with the most valuable reference for decision making on the most critical urban issues, such as transportation, public health, social segregation, crime, as well as urban landscape design. Even though big data dominates current urban studies, the constraints of this particular format of datasets have not diminished due to the complexity of cities. Although as mentioned earlier that the analysis of general urban form in early planning stages has shifted from qualitative to quantitative, the real issue about the planning process is beyond the data. On the one hand, the data is objective due to its format as numbers, but, on the other hand, the data is subjective and biased since it fails to capture the reason or meaning of the numbers. As such, the data can only serve as one criterion supporting planning decision making. This research provides a practical approach to integrate the new types of urban data into planning decision support, offering new insights into how urban data can be utilized in urban planning practices.

In terms of the case of Xi'an, the historic city is confronting multidimensional challenges derived from the intense urbanization process, bringing up numerous construction and reconstruction projects within the city's boundary. Based on this research, one of the underlying guiding principles for all the undergoing and upcoming urban planning projects is to examine the existing urban structure of Xi'an from both global and local scale as the baseline study for consideration, because the integrated urban form can convey both urban gene information from the past and urban tissue information that is functioning at present. In other words, for cities like Xi'an, the understanding of urban form is beneficial for balancing the legacy from the past and the advantages of development. Furthermore, the urban form transformation has changed the urban structure of the city, especially areas beyond the 2nd ring road, creating urban areas that lack the city's quintessential cultural features. This transition is inevitable in the contemporary urbanization process, but the planners are able to calibrate the direction of the development, especially for new growth in the urban sprawl and expansion. By performing the method proposed in this research, the planners can examine whether the new schemes for urban development make the city more connected in general as well as what are the implications of the new urban development, thereby adjusting their planning schemes accordingly.

In addition, this research is applicable in a broad context beyond the city of Xi'an. To be specific, same as the Space Syntax method that has been applied worldwide, the method of this research is also applicable for Canadian cities, particularly for early analytical stages such as planning studies and the strategic planning. However, since the urban planning of Canadian cities is primarily car-oriented, it will be interesting to explore the difference between the urban form of Canadian cities with that of Chinese cities. Last but not the least, by combing the theoretical discussion and the proposed method, this research is beneficial for knowledge transfer from planning academia to professional practice, advancing the collaboration of planning education and planning practice.

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Appendices

Appendix 1: Python Snippet

```
# -*-coding:utf-8-*-
import requests
import json
import math
import os

def Bounds(part):
#specify the bounds of the research area by setting the corrdinates of two diagonal points
	cor_1 = [34.235800,108.895200]
	cor_2 = [34.317000,109.004000]
	dx = (cor_2[0] - cor_1[0])/part
	dy = (cor_2[1] - cor_1[1])/part
	all_bounds = []

	for i in range(part):
		for j in range (part):
			cor = [cor_1[0] + dx * i, cor_1[1] + dy * j]
			bounds = str(cor[0]),str(cor[1]),str(cor[0]+dx),str(cor[1]+dy)
			all_bounds.append(bounds)
	print("number of coordinats：" + str(len(all_bounds)) + str(all_bounds))
	return all_bounds

def data_to_result(query,new_url):
#decifering the data to structured data
	r = requests.get(new_url)
	Json = r.json()
	with open( query + '.txt','a') as f:
		for item in Json['results']:
			if 'tag' in item['detail_info']:
				jname = item['name']
				jtag = item['detail_info']['tag']
				jlat = item['location']['lat']
				jlng = item['location']['lng']
				data = jname+','+jtag+','+str(jlat)+','+str(jlng)+'\n'
			else:
				jname = item['name']
				jtag = 'NA'
				jlat = item['location']['lat']
				jlng = item['location']['lng']
				data = jname+','+jtag+','+str(jlat)+','+str(jlng)+'\n'
			f.write(data)
		print('data saved to:' + query + '.txt')

def page_num(url):
```

```
        r = requests.get(url)
        j = r.json()
        total = j['total']
        Page_num = math.ceil(total/20)
        return Page_num

def distributed_get(all_bounds,query,page_num):
        new_urls = []
        for bound in all_bounds:
                print(bound)
                url = 'http://api.map.baidu.com/place/v2/search?query=' + query + '&bounds=' +
",".join(bound) + '&page_size=20&page_num=0&output=json&ak=***'
                print(url)
                if page_num(url) == 20:
                        print('part too small!')
                        return 0
                else:
                        for i in range(page_num(url)):
                                urls = 'http://api.map.baidu.com/place/v2/search?query=' + query +
'&bounds=' + ",".join(bound) + '&page_size=20&page_num=' + str(i) + '&output=json&ak=***'
                                new_urls.append(urls)
                        print('number of new URLs:'+ str(len(new_urls)))
        return new_urls

def main():
        print('data saved to:' + os.getcwd())
        # parameter can be specified for the number of subsections of the area
        part = 4
        # input the query information as specified by BaiduMap API and the input must be Chinese. For
example, the '公交站' means 'bus station'
        query = '公交站'
        all_bounds = Bounds(part)
        new_urls = distributed_get(all_bounds,query,page_num)
        if new_urls == 0:
                print('pleas try again')
        else:
                for new_url in new_urls:
                        print('retrieving information from:' + new_url)
                        data_to_result(query,new_url)


if __name__ == '__main__':
        main()
```

Appendix 2: Gate Observation Table

	GATE NUMBER	TIME		NOTE
Age	Youth	Adult	Older	*Weather* *Functionality*
Pedestrian				
Cyclist				
Total				