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Functional Changing Pattern of Two Selected Streets in Milan:

a Study Based on Multi-source Data

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Abstract

Streets have been the base of city lives. Unlike building space, which is often endowed with one or several relatively fixed functions after construction, street function changes in time and space with the use of land and buildings linked to it.

Street function changes under time flow consciousness are traditionally defined as 'composite function' and 'shared space' and have been studied through methods such as observation and questionnaire rather than quantitative means. With the help of development in big geo-data, this study quantifies the spatial and temporal dynamics of street functions and functional linkages, expanding the scope of traditional methods to a bigger scale by using multi-source data.

This research has collected data from Open Street Map, Google Popular Times and Foursquare to study the functional changing patterns of streets in San Babila and China Town- Porta Nuova areas. 'Network interface model' is built to connect information from POIs to streets. Two definitions of 'function of streets' are given: from limited sense, 'function of street' is understood as visible functions that provide products or services; in general terms, 'function of street' is defined as the functional connectivity of streets which are invisible in physical space.

The selected streets are grouped into different functional changing patterns through K-means clustering from two definitions of 'function of streets' respectively. Afterwards, factors that can influence functional changing patterns are discussed qualitatively and quantitatively by combination of other sources of data.

From limited sense, the streets are clustered into six functional changing patterns; whereas in general terms, the streets are clustered into three, three and five changing patterns in functional connectivity within the streets, within 300m walking distance and within 500m walking distance respectively. After clustering of the functional changing patterns, it is also discovered that the functional changing patterns of streets are result of combination of many factors. How these proposed factors influence functional changing patterns of streets and how the result can be applied in practices are also given in the end.

Keywords: Street function, Changing pattern, Multi-source Data

Astratto

Le strade sono state la base della vita della città. A differenza dello spazio edilizio, che è spesso dotato di una o più funzioni relativamente fisse dopo la costruzione, la funzione stradale cambia nel tempo e nello spazio con l'uso di terreni e edifici ad esso collegati.

I cambiamenti della funzione di strada nella coscienza del flusso temporale sono tradizionalmente definiti come "funzione composita" e "spazio condiviso" e sono stati studiati attraverso metodi come l'osservazione e il questionario piuttosto che mezzi quantitativi. Con l'aiuto dello sviluppo di grandi geo-dati, questo studio quantifica la dinamica spaziale e temporale delle funzioni di strada e dei collegamenti funzionali, ampliando l'ambito dei metodi tradizionali su una scala più ampia utilizzando dati multi-source.

Questa ricerca ha raccolto dati da Open Street Map, Google Popular Times e Foursquare per studiare i modelli funzionali mutevoli delle strade nelle aree di San Babila e China Town-Porta Nuova. Il "modello di interfaccia di rete" è stato creato per connettere informazioni dai PDI alle strade. Vengono fornite due definizioni di "funzione di strade": dal senso limitato, "funzione di strada" è intesa come funzioni visibili che forniscono prodotti o servizi; in termini generali, la "funzione della strada" è definita come la connettività funzionale delle strade invisibili nello spazio fisico.

Le strade selezionate sono raggruppate in diversi schemi di cambiamento funzionale tramite K-significa raggruppamento da due definizioni rispettivamente di "funzione di strade". Successivamente, i fattori che possono influenzare i modelli di cambiamento funzionale sono discussi qualitativamente e quantitativamente dalla combinazione di altre fonti di dati.

Da un senso limitato, le strade sono raggruppate in sei modelli mutevoli funzionali; mentre in termini generali, le strade sono raggruppate in tre, tre e cinque modelli mutevoli nella connettività funzionale all'interno delle strade, rispettivamente a 300m a piedi e 500m a piedi. Dopo il raggruppamento dei modelli funzionali mutevoli, si scopre anche che i modelli funzionali mutevoli delle strade sono il risultato della combinazione di molti fattori. Alla fine vengono anche indicati in che modo questi fattori proposti influenzano i cambiamenti funzionali delle strade e come il risultato può essere applicato nelle pratiche.

Parole chiave: funzione Street, modifica del modello, dati multi-sorgente

Chapter 1 Introductions

1.1 Background

1. Street establishes the inner link of urban function, and is also the carrier of residents' lives:

In daily lives, streets have been the base of people’s social circle by providing connections and have affected life quality of people. Street is the basic spatial element of human and logistics’ movement. Whether from its physical meaning or people's cognitive perspective, street is the key to link urban functions in the city. In recent years, under the background of economic transformation and smart growth, streets in many cities around the world have been revived, and the importance of streets has become more and more well known to the public.

2. Function of streets are changing with people’s activities:

Unlike building space, which is often endowed with one or several relatively fixed functions after construction, street function changes in time and space with the use of land and buildings linked to it. On the one hand, the street as a link between the external space of the building provides a channel for the flow of people. On the other hand, people's activities in the land connected by the street cause changes in the function of the street. This change is usually expressed as ‘composite function’ and ‘shared space’, which includes two parts: time, and space. Temporally, street segments have different functions and functional connections at different times; spatially, a certain function has different spatial emphasis at different times.

3. The era of data-based design calls for a grasp of temporal and spatial changes:

The ultimate object of urban planning is space. In planning practice, streets are the basic spatial elements connecting spatial functions. When planners configure the relationship between spatial functions and organizational functions, and imagine the exchange of people in the environment, they need to take streets as the carrier. The use of big data makes the designer's grasp of space more precise, which is not only limited to the grasp of a static state, but also requires a dual-dimensional grasp of time and space.

4. The application of big data provides support for spatial and temporal change perception of urban street functions and functional links:

In recent years, the rapid development of mobile location, wireless communication and mobile Internet technology and the popularity of location-aware mobile devices have brought a large amount of data with individual tags and temporal and spatial semantic information. With the development of Web 2.0 and mobile Internet, users can perceive urban geographic environment through online social media platform, so that they can share views, feelings and knowledge at any time. Since the traditional social media platform joined the location sharing function, the social media data has increased exponentially. These data reflect the location, use and time information of urban spatial users, and have a wide range of uses.

Although the spatial and temporal changes of street functions are recognized by planning scholars and adopted by planning practitioners through the methods of composite function design, there has been a lack of effective means to measure such changes for a long time. Media check-in data can obtain a real-time model because it has spatial point information, time information, user personal information, etc. The use of big geo-data provides effective data support for the study of spatial and temporal changes of street functions and functional connectivity.

5. Research on functional changing of streets is consistent with the concept of complete street, which is a leading trend in urban studies

It is the direction of people's efforts to build a shared street that can accommodate both pedestrians and pedestrians, taking into account efficiency and vitality at the same time. Therefore, it is urgent to break through the diaphragm of various research fields and form a complete study of street interface. Effective measurement of street interface form is the basis of research on street planning, control and urban microclimate. The street interface is obviously restricted and influenced by regional climate, historical and cultural traditions. Therefore, the long-term way to build a better city is to integrate the multi-dimensional research framework of urban form, environmental behavior, spatial cognition, regional climate, history and culture, to conduct a more comprehensive study of street interface, and to develop a more systematic quantitative measurement method.

1.2 Research Significance

1. Quantifying the spatial and temporal changes of street functions

In previous studies, street function changes under time flow consciousness are usually defined as "composite function" and "shared space". Scholars study street function characteristics and users' experience through traditional methods such as observation and questionnaire, lacking quantitative research means. This study quantifies the spatial and temporal changes of street functions and functional linkages, expanding the scope of traditional methods to block and city scales, saving manpower and material resources which is a certain degree of innovation.

2. Research based on people's behavior

In this research, it is considered that people's usage of streets is making the function of streets changing with time and people's usage is by accepting products and services or by occupying the space along the streets. Additionally, in consideration of 'function of street' in general terms, this research is using people's movement along the streets to define the connectivity range by network analysis.

3. Widespread application in planning practice

This research has provided data basis for the adjustment of street function connection at the urban level, the planning of urban activities and the replacement and renewal of urban function in the outer space of the building at the district level. In the practical level of planning and design, it conforms to the application prospects of media check-in data and other big data in the direction of data-based design.

1.3 Technology Roadmap

The technology roadmap of the research is shown in Fig 1.3-1. As is shown in the image, the whole dissertation is made up of mainly five parts, with the third part as main body of the research which is developed based on definition of function of streets – from limited sense and in general terms. The main body of the research contains three parts in accordance with Chapter 3 to Chapter 6, which are about calculation of function of streets (Chapter3); calculation of functional changing patterns of streets (Chapter 4, Chapter5) and discovering factors that influence the functional changing patterns (Chapter 6).

1.4 Research Framework

This research is made of seven chapters.

Chapter 1 introduces the background of the research, the significance of this research and how this research will be conducted.

Chapter 2 listed out related literatures that have strong relationship with this research. Four aspects of literature are given in this part: first is literature review about function of streets, its related theory, development and research trend nowadays; second is literature review about comprehensive use of big data, its key technique and research focus; third is a review on recent mainstream study related with streets, about the methods used in these researches, the limitations and possible progresses; fourth is about existed studies about the drivers of urban dynamics.

Chapter 3 provides the methodology used to get functional changing patterns and their motivations in this research based on previous research. This part of the research makes descriptions of the research problems and main hypothesis with feasibility analysis. Then, how the data is collected, managed and used is given.

Chapter 4 and Chapter 5 are summarizing functional changing patterns of streets, from limited sense and in general terms respectively.

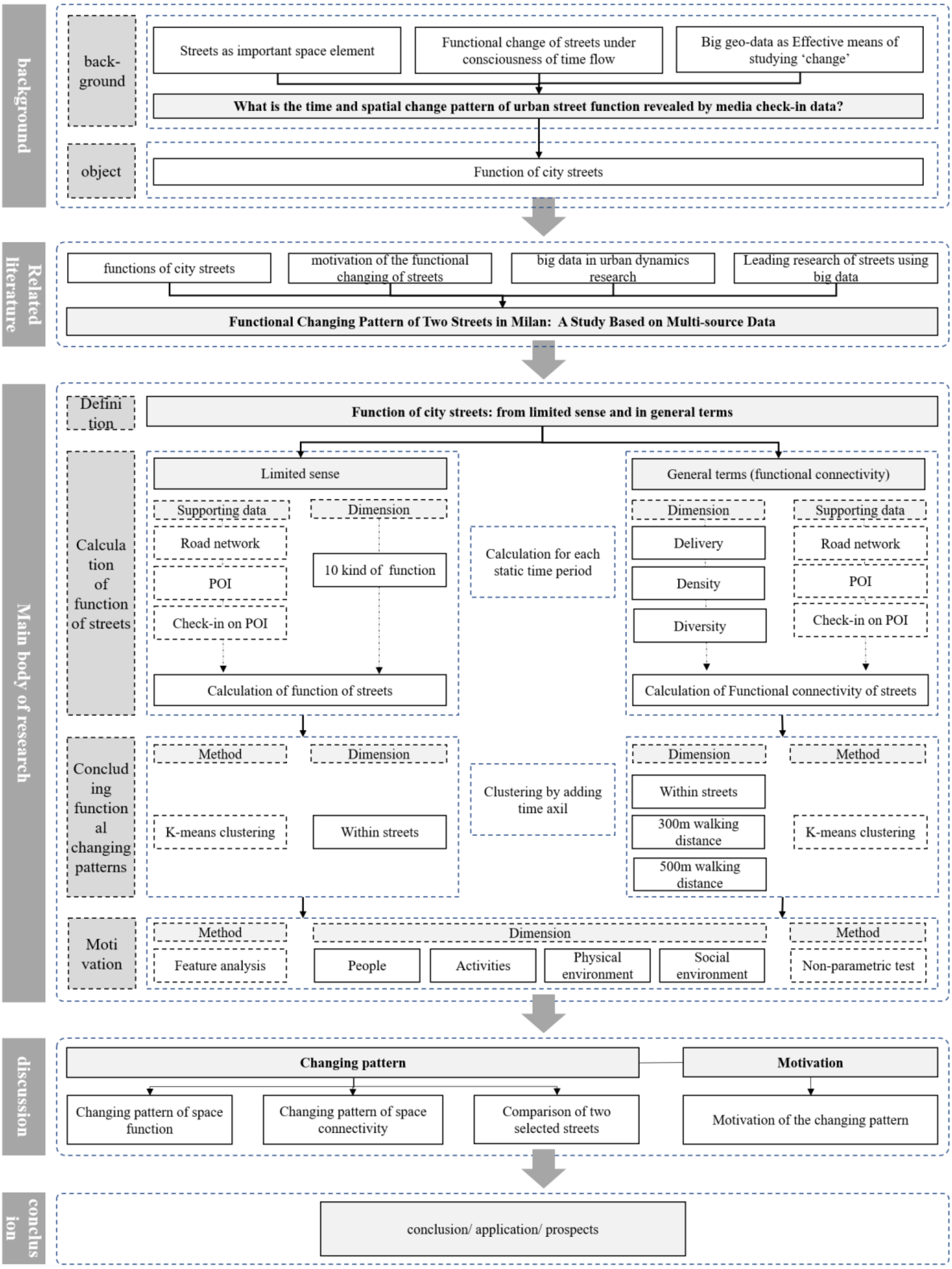


Fig 1.3-1 technology roadmap

Discovery of factors that influence functional changing patterns is made in Chapter 6. This chapter is developed by three parts: first is factors that make difference between the two selected areas; second is factors that influence functional changing patterns of streets from limited sense and finally is factors that influence functional changing patterns of streets in general terms. Both qualitative and quantitative methods are used during the process of analysis.

The final chapter of this research is summarizing the results of the research, namely, functional changing patterns and the motivations of the functional changings. Besides, limitation of the research as well as possible application and future prospects of the research are also given in this chapter.

Chapter 2 Literature Review

This study is mainly based on four aspects of literature review. First is literature review about function of streets, its related theory, development and research trend nowadays; second is literature review about comprehensive use of big data, its key technique and research focus; third is a review on recent mainstream study related with streets, about the methods used in these researches, the limitations and possible progresses; fourth is about existed studies about the drivers of urban dynamics. The summary of this chapter gives possibility of the conduct of the research and the main methods be used in the end.

2.1 Literature Review about Functions of City Streets

1. Thesis Development

With the development of production, the modern city is born out of the traditional city, forming a huge complex system composed of multiple elements. Many scholars have studied urban phenomena from various levels and explored urban development from different perspectives. Street as an extremely important part of the city, many urban scholars have injected a lot of effort into it, and the theoretical system of urban street space is also increasingly perfect.

Urban streets are the skeleton of urban space. Contemporary construction and development have been running through the whole history of urban development in the modern sense. With the development of motorized transportation and the advancement of urbanization, the phenomenon of automobile encroaching on the city is becoming more and more serious, resulting in the disharmony of street space in the city. Travel traffic is gradually developed, but the living environment is rapidly deteriorating. Later, people gradually realize that urban street space is an indispensable stage of human daily life. However, in the contemporary cities with more and more diverse living cultures, when the turbulent undercurrent gradually emerges, people realize that streets should be an organic growth body with comprehensive coordination and tolerance of economy, environment and society.

Since *the Athens Charter* put forward the concept of functional zoning, the spatial layout of foreign cities has evolved around functional zoning: from functional separation, to functional mixing, and then to social integration. This process also implies the evolution of street functions. Generally speaking, the development of contemporary urban street construction has gone through three stages with different functions highlighted: providing fast tracks in early 20th century; functioning as composite space in 1960s and integration in 1980s (Tab 2.1-1).

Tab 2.1-1 Three stages of street development and construction

years	function of streets	main opinions
early 20th century	fast tracks	Street function is mainly to undertake urban traffic; Pursue hierarchy and instrumentalization
1960s	composite space	Living blocks and multi-functional streets; Multiple modes of transportation coexist.

1980s	integration	Vigorous social communication space; Multi-factor coordination and symbiosis pursue sustainable development.

a. Stage of 'technicalism': fast tracks

At the beginning of the 20th century, due to the emergence of motor vehicles, the dominant mode of urban travel gradually changed from walking to driving, and the construction of urban streets began to cater to the traffic of motor vehicles. During this period, the urban street system changed rapidly from the pure pedestrian network to the traffic separation mode of vehicle diversion, and "speed pursuit" became the main factor of urban street reconstruction and renewal.

Modern traffic occupies the street space strongly and domineeringly. This design idea of 'more vehicles but less people' has led to unprecedented drastic impact on the urban slow-moving environment. Faced with the increasingly acute contradiction between pedestrians and vehicles, European and American countries have divided the pavements on the streets. This separation of pedestrians and vehicles has become the earliest measure to improve the pedestrian environment in modern cities. Under the irresistible trend that motor traffic gradually occupies the street space, Meister, Germany, put forward the idea of classifying and grading streets, dividing urban streets into main roads serving motor traffic and living blocks serving residential areas. At the same time, it is suggested to reduce the traffic in living blocks to improve mobility. The contradiction between traffic and walking environment.

In *Bright City*, the pioneer of modernism, Corbusier envisioned the viaduct road traffic system of increasing road width, reducing road intersections and organizing three-dimensional layering. Since then, the street design of engineering technology has become the mainstream of urban street design. Especially in the United States with high degree of motorization, urban road network is basically planned and designed according to the development model of cars, which not only consumes a lot of financial resources, but also has huge potential safety hazards. Under the circumstance of serious disturbance to residents' living environment, Perry put forward 'neighborhood unit', trying to separate the traffic network of people and vehicles on a large scale and for a long time, and thus advocating the internalization of residents' living blocks. While reducing the density of road network, it still relies on the development mode of motor traffic efficiency, which is doomed to end in failure from the beginning.

During this period, cars were invented and gradually promoted. People gave almost perfect optimistic expectations for motor traffic, regarded the traffic function of streets as a unique planning element, simplified the life in cities, and then blindly worshipped and crazily pursued the efficiency of modern commuting. Faced with the situation that the street space is occupied by motor vehicles, the walking environment is greatly damaged and the residents' daily life is excluded, a series of concepts and measures such as pedestrian-vehicle separation, serving the living blocks in residential areas, and internal pedestrian neighborhood communities are put forward and put into practice.

During this period, Concern about living space on street has gradually come into people's vision. However, under the background of street traffic motorization and efficiency, people are mainly concerned about how to solve the problem of road traffic efficiency. The original comfortable nature of daily life of the humanized street space is inevitably transformed into car-specific roadways, and ultimately can not stop the decline of the characteristics of street life.

b. Stage of 'Humanism': composite space

In the 1960s, private cars have become the symbol of urban prosperity. The development of motor traffic basically controls the form of road system. Simple highways have disintegrated and replaced the traditional humanized urban streets. While the public environment of the city has been greatly damaged, the efficiency of the city has also fallen into a state of out of control. On the contrary, the streets became overcrowded. The abundant daily life activities carried by urban street space are being cut down, and the street scenes in central and residential areas are becoming increasingly depressed and declining. At this time, the concept of "giving the street back to pedestrians" has quietly sprouted and gradually become the consensus of people. Humanistic trend of thought has arisen in response to the situation, and launched a fierce attack on the technocratic urban planning thought with "functional zoning" as the core.

In 1961, Jane Jacobs published *The Death and Life of Great American Cities* which is a watershed in the discussion of street functions. She proposed that "streets are lively, cities are lively, streets are dull, and cities are dull", believing that dynamic streets can not only have simple traffic functions. Using sociological methods and from a pedestrian's point of view, Jacobs observed and experienced the details of life in the city streets in detail. She found that the vitality of the city was concentrated on the streets, and it was diversity that created the vitality of the streets. In this book, four necessary conditions are put forward to promote the diversity of blocks: mixing of main functions, small blocks, old buildings, and density. In addition, on the basis of observing how residents use street space in their real daily life, the author examines some aspects of the decline and renewal of streets, and puts forward the concepts of 'self-defense' and 'street eye'. Jacobs has successfully blocked the Greenwich Village renovation project in New York and avoided highway crossing by using his professional background, network, appeal and social resources of the local middle-class residents.[5]

From this book, a wide discussion on street construction was launched, among which many schools of thoughts appear during this period.

In 1976, in *Urban Design*, E. N. Bacon believed that the diversity of urban residents determined the form of the city, and proposed the concept of "simultaneous movement of various systems", namely, the activity path and transportation route of urban residents. A clearly expressed movement system can grasp people's thoughts and generate centripetal force. Bacon believed that it was necessary to have a deeper and wider understanding of the diverse behavior and interaction of residents in order to establish a practical movement route with a large number of people and maintain harmony in urban design.

In 1971, Jan Gehl published *Life Between Buildings*, which examines public activity space from the starting point of human activities, dividing human activities into three categories: necessity activities, spontaneous activities and social activities. [6] The author finds that the frequency and types of outdoor activities are closely related to the quality of outdoor space, and the methods of promoting social interaction activities are analyzed in detail from multiple spatial levels. The planning decision-making is discussed in the aspects of opening and closing of streets and buildings, space scale and distribution, and the detailed design of slow-moving space and activity place is put forward. In the book *Street and Square*, the author Cliff Mumford, by retrospecting history and combining with many excellent cases, emphatically discusses the form and function of street and square, which are two kinds of urban public places, from the aspects of function, structure and symbolism, and emphasizes their important significance in urban life.[7] Kevin Lynch believes that people's understanding of the city is a comprehensive impression formed by the interaction of different senses on the city. In *Image of the city*, it is pointed out that people form an impression of the whole city by observing the streets, so the streets are the dominant elements in the city. Lynch reveals a characteristic of street space, trying to organize our surroundings and give streets and cities a suitable shape.[8]

In 1975, Yoshinobu Ashihara published *External Space Design*. The author considers that a pleasant street space environment must be an open space with appropriate aspect ratio and distinct layers, and puts forward such spatial layers as public-semi-public-private. In the discussion of design techniques, the paper discusses how to use the concepts of additive space, subtractive space, positive space and negative space to change the modulus of 20-25 meters in order to obtain a lively atmosphere.[9] In 1979, in his book *The Aesthetic Townscape*, Yoshinobu Ashihara analyzed the proportion of width and height of streets in detail, and put forward the concepts of 'first contour line' and 'second contour line' of buildings. Combining street space with architectural form, the whole street space is designed on the basis of human space vision. The influence of architectural layout on the formation of street space is discussed, and the value of small space is advocated.[10]

While calling for the return of street space to humanism, many scholars also pay attention to the control of motor traffic. British scholar Tripp took the lead in putting forward the concept of "functional block", advocating the classification of road traffic, and dividing functional areas into sub-trunk roads to strictly control traffic. It can be said that Tripp was the first person to come up with the idea of modern traffic calm. In 1963, the Buchanan Working Group on Urban Transportation Issues put forward the idea of 'Environmental Functional Block' on the basis of 'Functional Block'. In a report on 'Urban Transport', Buchanan Working Group revealed the traffic problems of the whole city, and put forward the concept of 'Street Environmental Capacity' for the first time. The report points out that street design should not only be based on "traffic capacity", but also on 'environmental capacity'. Environmental quality is inversely proportional to traffic volume. [11] Whether it is 'functional block' or 'environmental functional block', its essence is based on the development model of motor traffic efficiency. It has many similarities with Perry's 'neighborhood unit', which connives the expansion of cars.

Influenced by the idea of "traffic calm" in Buchanan Report, the Netherlands has carried out the concept of walking in residential area planning: combining bicycle paths with sidewalks, planting trees in new open spaces and setting up street facilities, and designing streets as end-to-end or gourd ports to restrict external motor traffic. Shape. In 1976, the law recognized the design as 'Woonerf'.[12] In the United States, the Urban Land Association published "Residential Streets" in 1974, calling for the lowering of local street standards and the adjustment of their functions so that they are not limited to purely motor transport functions. The idea of sharing people and vehicles in street space is beginning to sprout. In 1983, Germany published the book Traffic Calming Cost, pointing out the good characteristics of shared space: reducing traffic flow, reducing traffic speed, and strengthening pedestrian use. In 1992, Carmen Haas put forward five goals of ‘Woonerf’ in his book Civilization Street: A Guide to Traffic Stabilization: A. Improve road safety; B. Reducing transit traffic; C. Reduce vehicle speed; D. Create more space; E. More space for trees, shrubs and flower beds. [13]

In this stage, automobiles have become an important part of urban life. While facilitating people's way of travel, they have impacted on the original urban structure. The abundant pedestrian activities and communication activities carried by streets have been weakening. Faced with the increasingly widespread phenomenon of indifference in cities, the conflict between technology and human nature has become increasingly acute. People gradually realize that street is a public place of great significance in the daily life of the city. It should be based on meeting people's needs, advocate humanized design, and emphasize the improvement of the quality of street life.

During this period, multi-functional Street gradually became the mainstream idea of street design, emphasizing the diversity of space and creating interesting space environment. Many scholars also tried hard to recover the flavor of street life from the aspects of street space characteristics, natural aesthetics, human activities and so on. Many projects and concepts such as ‘diversity’, ‘simultaneous movement systems’, ‘spontaneous activities’, ‘second contour line’, ‘functional blocks’, ‘environmental functional blocks’ and ‘Woonerf’ have been put forward continuously. Many countries have begun to limit the speed of motor vehicles reasonably. Streets have gradually changed from simple traffic corridors to diversified complex spaces, but the trend of motor traffic supremacy is still unable to stop, ‘pedestrians first’ is still a dream.

c. Stage of ‘Neo-rationalism’: integration

In the 1980s, a series of problems brought by motorized transportation broke through the endurance limit of the Metropolitan Central area, and the phenomenon of uncontrolled suburbanization prevailed in metropolitan areas. Many scholars have sought ways to curb urban sprawl, ease the contradictions between urban environment and solve urban social contradictions, so as to bring about sustainability and high-quality city life.

In the 1970s and 1980s, inspired by the ‘Woonerf’ model, the Western Tranquility Plan was launched in Germany, using a new traffic management method to advocate harmonious coexistence between people and vehicles. In order to improve the safety, comfort and habitability of streets, a series of measures are planned, such as restricting traffic speed, reducing total traffic volume, preventing traffic accidents and reducing traffic pollution. With the accumulation of fruitful practice, the application scope of the plan has gradually extended from the original residential blocks to the whole urban road. In the 1980s, the theory of car-pedestrian sharing opened up a new field of planning research, and gradually replaced the research of car-pedestrian separation and walking priority. In his book The Formation of Streets and Towns, Sosworth and Ben Joseph pointed out that the basic idea of sharing streets is to construct a unity, emphasizing community and residential users.[14] Shared streets focus on pedestrian-oriented design, providing space for communication and rest; subordinate mobile traffic to provide traffic and parking space; and place pedestrians and cars on a shared level, hoping that they can coexist in harmony. The book summarizes a series of features related to shared streets, such as residential public space, no encouragement of unimpeded traffic, no strict demarcation between roadways and sidewalks, and so on.

In the 1990s, the New Urbanism Movement, a widely recognized urban design movement, led the urban construction to a healthy development trend. New urbanism holds that street space should become a vibrant social place and encourage people to engage in various kinds of communication activities on the street. Its ideological core is to transform the old city center with modern needs, that is, to combine traditional value standards with the real life environment, and to put new functions to meet contemporary needs. In order to reduce the dependence on cars, the "traditional neighborhood development model" and "bus-led development model" were proposed.

While striving to improve the urban living environment, scholars are actively exploring the sustainable road of street development and devoting themselves to improving people's social value. In *Finding Lost Space – Theory of Urban Design*, Roger Trancik reviews the space development in the 20th century and believes that the historical model of urban open space is square and street. By reviewing the essence of traditional urban space, it is found that the loss of street structure principle makes the social function of traditional urban streets shrink gradually. Trancik classifies the main theories and comments on solving modern urban crisis into three categories: graph-bottom theory, connection theory and place theory, and points out that good spatial design must integrate these three theories.[15] In *The Great Street*, Allan B. Jacobs compares hundreds of streets around the world to find the success factors behind those "Great Streets". The author points out the criteria of great streets: conducive to the formation of neighborhood relations, followed by comfortable and safe space environment.[16] In the book *Inclusive Urban Design – Streets for Life*, Elizabeth Burton argues that the lack of environmental inclusiveness contributes to the "incompetence" of the elderly and the disabled.[17] Taking the elderly's feelings as the starting point, the author explains how they experience the neighborhood relationship of the community and the frequency, time and reason of using streets, and expounds some basic principles of designing inclusive living streets.

At this stage, due to the excessive prosperity of motor traffic, many urban problems, including traffic safety and environmental pollution, have arisen in large areas of decline and complex social problems. Facing the depression of the central area and the spread of suburbanization, European and American countries have to find healthy ways to revive the development of the central area. At the same time, the humanistic spirit of academic circles has gradually matured. It not only pays attention to the environmental characteristics of cultural venues, but also emphasizes the dialogue of people in the space. The street space has gradually evolved from the former motor vehicles crowd out pedestrians to encourage pedestrian activities. The government began to pay more attention to the ecological environment, return the pedestrian space and other functions, improve the road environment for pedestrians, realize the humanization of urban streets, and pursue the sustainability of street development. The Street itself has changed from the previous dispute between ‘traffic priority’ and ‘walking priority’ to ‘people-car sharing’, showing a more inclusive attitude, Emphasizing Harmonious coexistence, and attaching importance to the harmonious and unified relationship between people and society, people and nature.

To sum up, street is the basic spatial element of human and logistics movement. Whether from its physical meaning or from the perspective of human's cognition in the city, street is the key to link the city's function. Urban functional area is the destination of urban activities, because people flow between different functional areas, forming a grid of functional communication media, which is the street system. Therefore, the function of the street itself is only "access", while other complex functions and social values come from the use of land and buildings linked to it.

2. Research hotspot and trend related with function of streets

In recent years, the concept of complete street has been paid more and more attention. It is the direction of people's efforts to build a shared street that can accommodate both pedestrians and pedestrians and take into account efficiency and vitality. Therefore, it is urgent to break through the diaphragm of various research fields and form a complete study of street.

Researches related with streets can be divided into four parts, firstly is research on Street Vitality: Taking "everyday life space" as the core idea of design, striving to enrich the use of streets; secondly is research on public space: Street space as an important public space in the city, creating comfortable activity space, with street planning and design methods as the focus; Third is research on Street Interface: Analyzing and researching the interface and facilities of street space to form a good street space form and landscape environment; and finally is research on planning management: innovating social management ideas and systems, adjusting planning policies and directions, and resolving spatial contradictions and group conflicts caused by complex social interests.

There are few direct studies on street function and its functional relationship using big data and quantitative methods in large scale. Y. Shen; K. Karimi (2016) defines the functional connectivity of streets, and puts forward calculation formulas from the perspective of activity density, functional diversity and spatial accessibility, and measures the functional connectivity of streets in central urban areas of Tianjin.[20] In Y. Shen's research, by conceptualizing an interface graph to reflect the interplay between land use points and the co-visual paths. A framework measured with a place-function signature is also introduced with a '3-Ds'model. '3-Ds' is a package with three principle dimensions of urban function network, including density, accessible diversity and delivery efficiency.

From the perspective of research methods, traditional research on streets lacks strong data support. Designers or sociologists rely on experience to think that the best way to build ideal streets is not necessarily consistent with the real needs of residents; but there are also many quantitative analysis methods, including field research, questionnaire survey, expert evaluating method. etc.[21, 22] Field research is mostly used in refined quantitative research. The range of study areas are often very small for the requirement of time and energy cost in study. The lack of quantitative research mainly comes from two aspects: on the one hand, in the past few years, restricted by the stage of urban development, the social attributes of streets are often ignored by people; on the other hand, it comes from the difficulty of data acquisition. In recent years, under the background of economic transformation and smart growth, streets in many cities around the world have been rejuvenated. The function of street public space has been recognized by people. Many cities around the world are also carrying out street rejuvenation practice.[23]

With the application of large geographic data, POI data, fuzzy matter-element model and GPS trajectory technology are gradually involved, which combines traditional research methods with advanced technical means.[24] Through the effective combination of subjectivity and objectivity, it provides a broader possibility for relevant research.

With regard to the case of quantitative study of street vitality, Y. Shen and Y. Long uses the big data of mobile signaling and takes Chengdu as an example to construct a set of index system for quantitative evaluation of street vitality, and explores the relationship between street vitality and the influencing factors of street vitality. Through the analysis, it is found that the vitality of public management and service streets is obviously restricted by the distance of Tianfu Square (the old city government), while the vitality of commercial service facilities streets is closely related to the subway entrance, while residential streets are more affected by the degree of functional mixing. Based on this analysis, the author also summarizes several ways to improve street vitality.[26] Similar research is conducted which quantitatively explores the street vibrancy of Beijing. street vibrancy is quantitatively evaluated at the street level. These factors range from function density, function diversity, accessibility to metro station, city commercial center and commercial complex, intersection density and bus station density, to street level and width etc.[27]

3. Consciousness of time-flowing in function of streets

The mode of human activity will affect the function of the street, which indicates the variability of the street function.[6] Manuel Castells put forward the concept of mobile space in *The Rise of Network Society* (1996). He pointed out that in the network composed of middle nodes and core, nodes and core may form hierarchical organization according to their relative importance in the network, and will change with the evolution of network activities. Space should not be regarded as a kind of passive static existence, it is regarded as a vivid force - Street as the external space formed by building enclosure, accompanied by changes in activity and connection function in the time dimension, is also in a dynamic state, and its function fluctuates along the time axis with changes of users.[28]

Although the specific contents of urban activities usually need to exist and display in the "exclusive" space area, they will also wander and guest-string in different zones delimited artificially because of their mutual bonding and complementarity, and urban activities themselves are also a variable value: constantly increasing and decreasing in types. Urban space has multiple attributes such as social, economic, ecological, political and physical forms, which leads to its complexity.[29] Regardless of this, no matter how technically classified, segmented, merged and integrated the urban space is, it is difficult to obtain an optimal spatial allocation and combination that always meets the dynamic needs of various aspects of modern urban activities.

Time is a useful measure to grasp the dynamic characteristics of urban activities. Measured by time dimension, many urban activities clearly show regular changes in a certain period of time, as well as metabolism and interaction in different time periods. That is to say, at a certain time node, a certain content of urban activity mainly occurs or remains at A place of urban space, but at another randomly selected time node, the content of such urban activity may have wandered or transferred to B place of the city, while the original specific form of urban activity at B place may have existed for a long time. Moving elsewhere --- so back and forth, urban activity and urban space remain intact and consistent. Activities such as residence, work, recreation and transportation undertaken by urban functions exist in different urban locations and change with time.

Since the city is a "space-time complex system", when planning urban space, we can not ignore the significance of time factor in it.[30] In the existing studies, the change of street function under the time flow consciousness is usually defined as "composite function" and "shared space". Scholars study the functional characteristics and use feelings of streets through traditional methods such as observation and questionnaire, lacking of quantitative research means.

2.2 Motivation of the Functional Changing of Streets

The mode of human activity will affect the function of streets, which shows the variability of street function. [7] In this sense, the motivation of functional changing of streets is more related with how people choose the streets.

In terms of when people choose the space, accumulation of people make urban vitality, which is similar to mechanism of how people choose streets. Among the many researches about factors of urban vitality, the framework put forward by Jane Jacobs in 1961 is the most acknowledged by scholars among similar factor systems. Sung summarized this theory by 4 main prerequisites and 2 subordinate conditions, which is shown in Tab 2.2-1[32]

Tab 2.2-1 factors that affect urban vitality by Jane Jacobs:

main prerequisites	mixture of land use	the existence of two or more basic types of land use;
	coexistence of building from different ages and styles	in Jane Jacobs age, construction of buildings with huge volume and single function was the trend. The diversity of buildings can help with the renovation of city environment, the maintenance of vitality and the development of economics;
	smaller scale of land	more crossings to slow speed of vehicles and shorten traveling distance to make more walkable environment;
	high density development	make intensive use of land based on diversity of the three aspects mentions before (function, style and age) to attract people's activity;
subordinate conditions	accessibility of city nodes	adequate public facilities realize the accumulation and evacuate of people;
	weaken of vacuum boundary of the city	rational control of 'vacuum boundary' with single function (e.g. universities, huge parking lots, and big urban parks), considering both benefits and negative effects.

From aspects of society, environment and culture influence, Landry's framework explores urban vitality differently from Jane Jacobs (Tab 2.2-2)

Tab 2.2-2 factors that affect urban vitality by Charles Landry

social vitality (Social interaction and activities at different levels)	communication and mobility; citizen pride and community spirit; inclusiveness; harmonious racial relations;
environmental vitality (ecological continuity in design)	sense of place; recognizability of architectures; connectivity between different city regions; street lighting and safety; accessibility;
cultural vitality (recognizability)	memory of place; traditions; festivals; handmade products and landmarks.

Based on the two frameworks, motivation of the functional changing of streets is concluded and further discussed by three aspects: people, activities and environments.

1. People

Facilities in streets usually attract people, but people also choose facilities nearby. From perspective of 'functions', Nelson categorized facilities in city into two kinds, one kind attracts users through its own attraction; the other kind makes use of the existing popularity around it.[43] The first kind is called 'producers'; the other kind is called 'accepters'. Producers are responsible for attracting people from long distance, and people attracted by producers usually decide what kind of people are using the 'accepters', which influence the use of streets in essence. From perspective of 'behavior' of people's nature, crowds of people are also attracting people—people tend to accumulate. [45,46] When there are many people and activities happening in certain places, diversity of the streets will certainly develop.

In this sense, the relationship between quantity of people and vitality is mutually reinforcing, which means people's choice are influencing functional changing of streets; accumulation of potential user of streets will influence people's choice as well.

Many researches are also studying what kind of composition of people are affecting use of space, among them 'heterogeneity' is one of the most important reasons. On the one hand, the complexity of people will arousing different kind of services aimed at them [31]; on the other hand, higher heterogeneity of people from different social background and class will also increase the the life experience in certain area. This view is validated by Halprin's[50] study about the relationship between people's behavior and their nationalities; as well as Hall's research about 15 kinds of behavior of white people and American Indian[51].

To be specific, 'heterogeneity' can be interpreted from origin of people. Maas divided people on streets into three kinds: native people; outsiders; and travelers [42]. 'Native people' refers to people who are the easiest to access to services in the area. 'Outsiders' refers to people who are not native people, but they are living in the area and using services inside. 'Travelers' refers to people who are from place outside the area. According to Maas, although outsiders and travelers are influencing streets, it is the native people who are key to define the functional changing.

Native people are composed of residents and workers. Workers are often considered as manifest factor which influence diversity of service, products, and services.[49] Jane Jacobs mentioned that workers increase diversity of service, products, and services in two ways: first is by consumption; second is by importing replacing products and fresh blood.[5] This view is validated by many other scholars. Barnett's research about shopping centers in Brooklyn found out that native users increase use of space far more than other users; Pushkarev and zupan's research also got similar results.

Additionally, 'heterogeneity' can also be interpreted from other angles, including racial/national; value; aesthetic and cultural angles.[42] These factors are also considered to have strong influence on uniqueness of places. What has to be emphasized is that accumulation of people is not a sufficient condition for adequate use of space.[25]

2. Activities

Functional changing of streets is defined people, but how can people use the space is also defined by kind of activities provided by space. Meier equals the success of cities with the capability of providing activities.[38]

Provided functions of streets is not changing with time but fixed at certain time period and space. People tend to be attracted by spaces that are continuously giving services and products, even if they are not participating. [45,46] Absolute number of provided activities is one of the attractiveness but not the most important. Mainstream quantitative measurement of functions provided by streets in recent years can be divided into three parts in recent researches.

(1) Mixed function intensity:

Mixed function intensity is the mixing degree of distribution of various functional entities in street space, reflecting the balance of different functional layout. It is not only an index of density, but also an index of spatial proximity. Quantification of Mixed Functional Indicators by Entropy Value Method.[18]

(2) Business Ratio:

The function of the first layer of the street interface will have a strong impact on the street environment, and the proportion of the business interface reflects the activity of the street interface. Among the many kinds of activities in the city, commercial activities are always the most attractive [80]. Cultural renovations are having similar effect as well.

(3) Accessibility of daily services:

The use of urban daily facilities is closely related to the purpose of citizens' travel. The types and distribution of facilities directly affect the quality of streets. Reasonable allocation of commercial services, education, leisure and transportation facilities will increase street usage. Facilities distribution is an important part of street space structure and land use. Reasonable facilities distribution objectively provides a variety of urban functions. Facilities accessibility can improve the utilization rate and service efficiency of citizens. It is an important manifestation of integrating resources with people.

3. Environments

a. Physical environment

physical environment has largely decided how people act in space.[31] Due to the transformation of researches related with streets from a 'city-based perspective' to a 'human-oriented perspective', physical environment should include quality of street space and human experience and activities besides traditional definition of physical environment.

--City-based perspective

(1) Land use

People access all kinds of land uses through streets, which means the land uses are affecting the functional changing of streets. Complexity of land use is considered as great help to accumulation of people.[56] The mode of the distribution pattern of land uses strongly affect how people act in space according to Krier and Rowe' research.[89]They think that the function of an area should be arranged according to different layers; the functions should be similar to each other but still have different standards; density; and preference. This kind of complexity should be satisfied not only from local level, but from the level of the whole city as well.

(2) Transportation

Streets are linked with each other [41], which is like a network linking public transport together. Accessibility provide possibility of the happening of consumption of products and activity, which forms the basis for attracting people.[86] Transportation system can meet residents' needs from different levels, through pedestrian and motor traffic.

From city level, cost of transportation become lowest when the high-density public transportation hubs, stations, and lines are forming a compound system network.[78] Jane Jacobs also emphasize the importance of transportation hubs and parks as public service nodes in carrying people to all kinds of products and activities.

Traffic mode:

Any traffic mode can not be separated from walking activities. There are contradictions and dependence between walking and modern means of transport in street space, and more of them are mutually reinforcing. Contradictions are manifested in that the operation of vehicles occupies street space and squeezes the walking environment; mutual promotion is manifested in the fact that various urban transport modes make up for the limitation of walking distance, extend and expand the scope of public activities of citizens; moreover, after people get off the bus, there is still no lack of walking activities, many of which are delayed. The purpose and task of renewal.

Station Connection:

It is the link of the transfer system. In order to effectively complete the transfer task, transfer stations are set up among various means of transport. Transportation transfer system is an integrated system for the continuous transformation of urban traffic modes. It is not only an organic organization between urban long-distance traffic and urban traffic, ground traffic and underground traffic, public traffic and private traffic, dynamic traffic and static traffic, but also the corresponding facilities construction.

Pedestrian-vehicle balance:

The essence of street is traffic function, its purpose is to carry traffic and pedestrian traffic. Citizens produce economic benefits through street shopping and social benefits by participating in public activities in the streets. Pedestrians are the active users of street space. Vehicles pass through the streets quickly without stopping, which is the passive users of street space. Harmonious overlap of pedestrian system and vehicle system can achieve vehicle efficiency and pedestrian safety. The balance between all. The traffic space in the street is too large, which compresses the pedestrian space, erodes the living space of the citizens, and affects the vitality of the street, thus reducing the quality of the street. Quantitative measurement of street pedestrian-vehicle balance can effectively reflect the balance relationship between pedestrians and vehicles.

--Human-oriented perspective

In Cockburn research, pedestrian should be firstly considered in urban design [19], which is supported by Jane Jacobs view that 'vitality is the walking activities on street'. When the most used travelling pattern is walking, a place will more likely to be active.[47]This is described by Karras as 'acquiring most requirements without a car'.[41] In Morency's research, if the short distance motor traveling are all replaced by walking, the traveling level of more than 8% of residents will be improved.

In recent years, research on street based on pedestrian view has become a hot topic, and related quantitative measurement methods are emerging. The main research fields involved are urban form, environmental behavior, spatial cognition.

(1) Parameters based on urban form

Interface density:

The density of the interface can be measured by the 'interface density' parameter. Some scholars have pointed out that 'interface density' refers to the ratio of the total projection surface width of a building (including fences and fences) with the length of the street or road on one side of a certain section of a street or road whose red line distance is less than 1/3 of the height.[60] Some studies have shown that street interface density can be used as an important reference index to measure the quality of street space. Keeping the interface density above 70% is a necessary condition for forming excellent street space.[61]

Wiring rate:

Concept of wiring rate originates from the concept of 'street wall' in American regionalization law, which can reflect the morphological characteristics of street interface in horizontal dimension to a certain extent.[62]

Alignment of buildings:

Alignment of buildings means "the ratio of the neat building interface dominated by the street to all the building interfaces". The molecule and the sticking rate are similar, but the denominator is obviously different. Its denominator is all along the street building interface, not the length of the street or the length of the block along the street red line.[63]

Sky view factor, SVF:

SVF refers to the ratio of the visible sky to the complete sky hemisphere of observation point.[64] In recent years, research scholars have proposed geometric analysis, projection calculation, GPS calculation, spherical calculation, shadow calculation and other methods to calculate sky openness. Method proposed by Oke T R. is the most popular one in urban studies. Firstly, the visual field factor of the street wall is defined, that is, in the street canyon, the proportion of the radiation emitted by the observation points absorbed by the street wall to the total radiation emitted (Fig 2.2-1). [65]

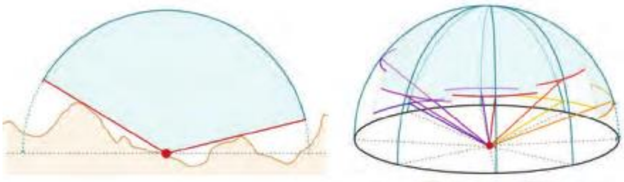


Fig2.2-1 definition of SVF

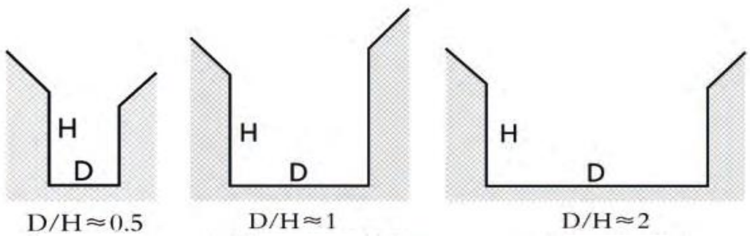
(red point: observation point; yellow area: obstacles; blue area: sky view. According to the calculation, 0 means that the sky is completely occluded, and 1 means that there is no occlusion.)

Sky exposure plane:

Sky exposure plane originated in the United States in 1916, the zoning law aims to effectively control the building interface along the street. In 1912, the concept of building height control proposed by William Atkinson, an American architect, first used the exposure surface control method to form a building control surface with a virtual inclined plane to ensure street lighting.[66] To some extent, this concept influenced the subsequent building height control bill. In 1916, New York City proposed the first regionalization law in the United States, which stipulated that the ratio of street width to street wall should be between 1:1 and 1:2.5.[67]

(2) parameters based on spatial cognition

D/H



(1) (2) (3)

Fig 2.2-2 D/H in Italy cities of different times

((1) Middle Ages; (2) Renaissance; (3) Baroque Period)

D/H refers to the ratio of street width to the height of buildings along the street. As early as in the 1850s-1870s when Haussmann renovated Paris, the proportion of the width of different classes of streets to the height of buildings on both sides was clearly defined. At the end of the 19th century, C. Sitte, an Austrian architect, made a thorough study of the aspect ratio of the square's interface. [68] He proposed that the minimum size of the square should be equal to the height of the main buildings around it, while the maximum size should not exceed twice its height.[68] Later, Japanese architect Yoshinobu Ashihara explicitly proposed the width-to-height ratio parameters of the street interface. He proposed that when D/H > 1, there would be a sense of distance with the increase of the ratio; when D/H < 1, there would be a sense of closeness with the decrease of the ratio; and when D/H = 1, there was a sense of symmetry between width and height. [10]

In Yoshinobu Ashihara's research about Italy, it is found that streets D/H_0.5 in the Middle Ages, D/H_1 in the Renaissance and D/H_2 in the Baroque Period. (Fig2.2-2) [10]

W/D:

Street width ratio (W/D) refers to the ratio of shop width to street width. Yoshinobu Ashihara believes that if stores smaller than the width of the street appear repeatedly, the street will be lively and lively; if the street is narrow and the storefronts along the street are long, it will destroy the lively atmosphere of the street space. Therefore, W/D < 1 is very important.[10]

Green vision ratio:

In recent years, with the deepening of the research on urban ecological environment and green space system [69], the measurement of three-dimensional green volume has become a new research trend. In 1987, scholar Aoki Yoji formally put forward the concept of 'green vision ratio' to express the proportion of green in people's vision. He argues that this physical quantity is considered in terms of human perception of the environment.[70]

In practical research, usually by means of photography, the selected sampling points are selected to shoot the selected objects in the direction perpendicular to the street. Afterwards, the greening information of the sampled landscape photographs is simplified, and the human visual field is approximated to a circle. The percentage of greening area in the whole circle area is called green looking ratio.[71] Different areas of greening will bring different psychological feelings, and the increase of green vision rate has a significant effect on people's stress relief.[72] Some scholars have pointed out that green vision rate can be used as an important quantitative indicator of environmental 'charm' and has a significant impact on people's perception of street safety.[73,74]

Interface openness

The parameters of 'interface openness' are mainly based on the quantitative description of the physical form of street interface, which may be different from people's visual perception.

Visual Entropy, VE

Entropy is a concept used to describe the degree of chaos within a system. In recent years, some scholars have used Visual Entropy (VE) to describe the subjective measurement of visual information complexity.[75] In the analysis of street landscape, visual entropy can reflect the attractive details and visual preferences of street landscape.

(3) Parameters based on environmental behavior

Transparency of interface

The research shows that the underlying interface of street has an important impact on street vitality. Jan Gehl argues that the diversity of the underlying interface has more influence on street activities than other environmental variables such as the width-to-height ratio and elevation difference of the street interface.[6] The transparency of the street surface at the ground floor of the building determines the degree of communication between the street and the building, outdoor and indoor activities. It is an important parameter affecting the vitality of the commercial street. The range of good transparency is usually between 60% and 70%.

Interface openness

The openness of street interface is used to describe the degree of openness or closure, but there is no uniform definition of this concept now. Openness = length of open interface / length of sidewalk * 100%. When the openness is 0%, the vertical interface is continuous glass or solid street wall. Its research shows that openness is negatively correlated with business activities, but positively correlated with social activities.

Density of stores

Store density refers to the number of entrances and exits per 100 m business unit in each block.[76] This parameter reflects the development intensity to a certain extent. The layout pattern of high-density small units makes stores and streets have more commercial exhibition areas, while providing more choices for pedestrians. Jan Gehl’s research shows that 15-25 blocks per 100 metres are the most dynamic and 10-14 are walking friendly. [77]

Signage density

Signage density refers to the ratio of the number of signs per 100 m in each block to the length of the street. Signboard density reflects the amount of commercial advertisements on the street to a certain extent. It is a parameter for people to judge the nature and feeling of the place subjectively. It can play a greater role in guiding pedestrians to feel strange space.

Percentage of grey space

The concept of ‘grey space’ was first put forward by Japanese architect Kisho Kurukawa, whose meaning is a transitional space between indoor and outdoor. In street research, the percentage of grey space refers to the ratio of the area extended by the building canopy and the total area of the street to the area of the building above the second floor per 100 m in each block. The percentage of grey space is positively correlated with commercial activities. Whether the grey space of the buildings along the street is continuous or not has a great influence on the commercial activities of pedestrians and the landscape along the street.

Street furniture

Street furniture refers to functional street furniture, including recreational seats, telephone booths, mailboxes, newsstands, mobile vending cars, vending machines, sanitation facilities, etc.

b. Social environment

(1) Inclusivity

At the beginning of the Industrial Revolution, residential cities entered a period of rapid development, and the blueprint of urban structure and planning experienced vicissitudes. With the advent of the automobile era, planning and architecture circles around the "people-oriented" and "car-based" launched a lot of theoretical research and practical discussion. After experiencing the phenomenon of "suburbanization" and all kinds of "big city diseases", scholars began to really pay attention to people, their living environment and their social interaction. The ideas of urban design and street space are developing in a pluralistic and holistic direction, and gradually bring cities back to the track of healthy development.

The concept of 'inclusive growth' is proposed by Asian Development Bank, advocating fairness and justice so that all sectors of society can enjoy the fruits of economic development fairly. With the broadening of the vision of humanism, people's livelihood has been paid more attention. Under the idea of "inclusiveness", the vision of urban planning discipline is becoming broader. While focusing on spatial quality and urban characteristics, the city as a whole is compatible with many disciplines, focusing on people, people's livelihood, social integration and common development.[33]

Inclusivity of streets should be thorough, in that everyone can participate in the activities on streets and get the feeling of belonging. According to Lynch. K, inclusivity is the understandability of what is happening on streets, which means everyone can participate.

(2) Safety

When someone go through a street, they are not changing its functions because he/she is not taking part in any activities on street. This means streets have to provide safe environment for people's staying. Researches show that safety has strong influence on people's choice to stay in open space as well.[31]

(3) Landmarks

Landmarks of a place is attracting people continuously. While landmarks are attracting people, they might also decrease diversity at the same time. Researches by many scholars have validated that some special groups of people's effects on spatial and functional layout.[49]

2.3 Literature Review about Big Data in Urban Dynamics Research

Quantitative analysis of urban dynamics has benefited greatly from the rapid development of massive big geo-data. By aggregating spatio-temporal behaviors from individual level, we can perceive the depiction of distributions, connections and procedures of urban socio-economic environment and thus understand the pattern of urban dynamics.

1. relationship between big data and urban dynamics

In recent years, the rapid development of mobile location, wireless communication and mobile Internet technology and the popularity of location-aware mobile computing devices have brought a huge amount of data with individual tags and temporal and spatial semantic information. These big geo-data which can describe individual behavior, such as social media data, mobile phone data, public transport data, taxi data and so on, provide a new means for people to quantitatively understand urban dynamics. They have also been extensively studied by scholars from the fields of computer science, geography, transportation and urban planning. [34-36]

2. Big data that reflects people's move

Traditional big data that are commonly used in smart city construction has Two obvious shortcomings: first, the lack of dynamic sensing of the city. The current smart city perception layer uses barcode, RFID, smart card, information terminal, etc. to identify the address, identity and static characteristics of the object, and at most to identify the state of the object at a certain time. It is a static sensing. However, the city is a high-speed operation of the aggregate, in its interior, the flow of people, logistics, capital and information are in a high-speed movement state. How to dynamically sense the city is a problem that must be solved in the construction of smart city; Secondly, human activities, such as human space-time behavior patterns, social relations, human-land interaction, are the core of the dynamic elements of the city, and the current construction of smart cities has the problem of insufficient attention to human beings.[36]

The greatest uniqueness of big geo-data lies in its information with two dimensions of time identification and spatial coordinates. Each record contains spatial and temporal markers that can be associated with individuals, reflecting the corresponding characteristics of human spatial and temporal behavior. For an individual, its spatial behavior has certain randomness and limited value. However, when the amount of data increases, the group behavior pattern reflected by mass samples at the aggregation level can show more obvious regularity. The spatial and temporal behavior regularity of human beings is related to the urban geographical environment, which can help us to reveal and understand the dynamics of the city.

Liu put forward the concept of 'social sensing' and its research framework in 2015, pointing out that social perception is the theory and method of studying the spatial and temporal behavior characteristics of human beings with the help of various geographic data, and then revealing the spatial and temporal distribution, connection and process of social and economic phenomena.[39]

The emergence of big geo-data with higher temporal resolution and lower spatial aggregation scale has brought unprecedented tremendous reform to the study of urban geography.[40] Within the framework of social sensing, the main research directions of integrating large geographic data to understand cities include: a. analyzing the function of urban land based on time-varying characteristics of activities[57];b. discovering urban spatial structure based on spatial interaction;[58,59]c. extracting geographic events or perceptions based on semantic data of social media. geographical environment [47,48].

There are many types of big data that reflect people's move, including mobile phone location data, public transport data, taxi GPS trajectory data, social media data and so on. These data are different in acquisition mode, spatial resolution, user attribute expression ability, activity semantic expression ability, trajectory integrity and so on. They also have their own characteristics in perceiving urban dynamics.

(1) Mobile Phone Data, MPD

Mobile Phone Data (MPD) is the most common type of large geographic data, which can be divided into call recording and signaling data.[36] Among them, the sampling frequency of call record data is low, which can reflect the relationship between users. It is often used for crowd partition and the construction of embedded spatial social network. The latter has high sampling frequency and no interactive information, which can often reconstruct the user's travel chain. When a user receives a call, the location of the base station that undertakes the communication service is automatically recorded. Typical mobile phone data contains user's anonymous ID, base station ID, longitude and latitude, call object ID, call time and other information. By recording the base station location sequence, researchers can extract individual space-time trajectory information, and then conduct related application analysis. MPD has the advantages of high population coverage, wide positioning range and suitable for large-scale acquisition, but at the same time, mobile phone data cannot record individual attribute information.[52] However, because mobile phone data belongs to passively collected location data (location can only be recorded when the user calls), the individual trajectory obtained is different from the actual trajectory.

Mobile phone data was initially used in individual mobile model modeling [53,54] and traffic analysis and simulation [55], and subsequently applied to regional and urban research. Because of the huge sample size and high coverage, mobile phone data can identify the spatial and temporal characteristics of cities at multiple scales, thus providing a basis for further spatial analysis and planning.

(2) Social Media Data, SMD

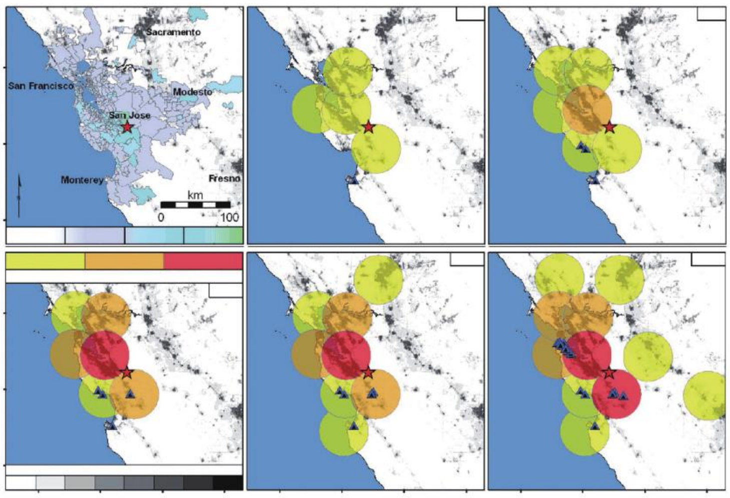


Fig 2.3-1 Monitoring the magnitude of earthquake using Twitter [91] (Earle et al., 2010)

Social media data contains not only accurate user check-in location information, but also user activity information, such as POI information, restaurants and shopping malls.

However, social media data has many known limitations, such as insufficient sample size, low individual sampling frequency, location information offset, etc.[79], but for the abundance of information contained researchers can obtain attribute information at the individual level through text mining, natural language processing, image recognition and other technologies, such as preferences, emotions, motivation, satisfaction and social networks.

SMD is sensitive to urban hotspot areas and events and has a variety of research scales. It is an effective record of socio-economic environment, special events and living conditions. SMD is widely used in regional structure analysis [87], urban planning and assessment [88], emergency response and other fields [90]. Fig 2.3-1 shows application of Twitter data in monitoring earthquake,[91] where the upper left corner provides the intensity map for USGS DYFI, while the remaining five panels show the spatial distribution of seismic intensity inferred by the number of monitoring inferences at different time nodes.

(3) Smart Card Data, SCD

Smart Card Data traces the movement information of urban population from public transit systems such as buses, metros and shared bicycles. It is a kind of mobile data with spatial and temporal identification. At present, public transport IC card has been widely used in the payment of transportation costs, recording the ID of the card switcher, bus line number, travel time, up and down stations, fees and other information. SCD can cover all age groups in the city, reflecting the real-time travel situation and commuting behavior of urban residents.

At the same time, because of its cost information, real-time updating and other advantages, it has been widely used in the study of urban population commuting [92], socio-economic environment [93] and urban structure [94].

Limitations of SCD are relatively manifest. Firstly, the amount of data is small and the continuity of trajectory is low; secondly, there is a deviation between the real place of departure and destination and the recorded site, which can not reflect the real purpose of travel; thirdly, there is a lack of individual attribute information of users, and finally, the activity type is relatively single.

(4) Taxi Trajectory

With the increasing complexity of urban traffic network, more and more vehicles are equipped with global positioning system to realize location monitoring and path navigation. At present, most of the taxi trajectory data are collected from floating taxi equipped with GPS and stored in text form. The information includes terminal unique ID, longitude and latitude, speed, course, passenger status, etc.

Taxi trajectory data is similar to SCD. It does not record the individual attributes of travelers, and the data representation is limited. It is often suitable for macro-urban dynamic research. Because of the high consistency between taxi trajectory data and road network, and the advantages of complete trajectory sampling and high spatial and temporal resolution, taxi trajectory data are often used to analyze urban traffic structure, travel mode and traffic flow prediction.[95]

Mining individual attributes, activities and movements, and spatial-temporal interaction at the aggregation level from large geographic data is the basis of urban research and planning practice in the era of big data. Some of the most typical large geographic data mentioned above have their own advantages and disadvantages in perceiving and understanding urban dynamics, and the applicable scenarios are also different. Table below summarizes advantages, disadvantage and possible application scenarios of the four kinds of big geo-data mentioned above.

Tab 2.3-1 advantages, disadvantage and possible application scenarios of big geo-data

Data	**Advantages**	**Disadvantages**	**Application scenarios**
Mobile Phone Data (MPD)	- high spatiotemporal resolution; - large sample size; - signaling data can provide individual travel chains; - call data can provide user call information	- no individual attribute information - information deviation - lost information cannot be compensated	- individual behavior patterns - clustering people - urban spatial structure and community discovery - urban functional distribution
Social Media Data (SMD)	- high spatiotemporal resolution; - easy real-time acquisition - rich individual attribute information - rich semantic information	- less sample size - inadequate representation of data - discontinuity of trajectory information	- individual behavior patterns - urban spatial structure and functional distribution - urban environmental assessment and place emotion - hot spot event discovery
Smart Card Data (SCD)	- real-time update - high population coverage - OD information integrity	- less sample size - real od geographical position deviation - no individual attribute information - limited by the planned urban traffic network	- urban spatial interaction and structure - urban commuting mode - evaluation and optimization of public transport
Taxi Trajectory	- high spatiotemporal resolution; - high trajectory integrity - OD information integrity	- high data redundancy - no individual attribute information - inadequate representation of data	- travel pattern mining - traffic simulation - urban spatial interaction and structure - urban spatial structure and functional distribution

3. Comprehensive use of big data in urban dynamics research and case studies

According to previous study, there are many types of big data, including POI data, mobile phone location data, public transport data, taxi GPS trajectory data, social media data and so on. These data are different in acquisition mode, spatial resolution, user attribute expression ability, activity semantics expression ability, trajectory integrity and so on. They also have their own characteristics in perceiving urban dynamics. Therefore, different data sources can complement each other because of their different spatial meanings which makes up for the disadvantage of traditional data.

According to the basic concepts of 'social sensing' research framework, when integrating large multi-source geographic data to study urban problems, it can be divided into two levels of "people" and "land". On the basis of studying static characteristics, the evolution characteristics of time dimension are added to understand urban dynamics. Therefore, the research of urban dynamic characteristics through comprehensive use of big data can start from the following three aspects: a. sensing of human dynamic behavior patterns, that is, perception of human movement, activities and social relations in a short time scale, is micro-level perception in both time and space; b. sensing of regional dynamic activities and linkages, through spatial aggregation of individual behavior patterns and long-term scale observation, to achieve urban expansion; c. the emotional and semantic sensing of place which forms a mapping between people's emotional perception and geographical location, and discovers more abundant human attributes of geographical space from big data.

a. Sensing of human dynamic behavior patterns

'People' is the most important dynamic element in a city. Sensing of human behavior is a crucial link in understanding the dynamics of a city. Big multi-source geo- data can reflect temporal and spatial behavior such as human movement and activities, show the characteristics of urban residents' activities in a short time, and reveal the short-term dynamics and laws of the city.

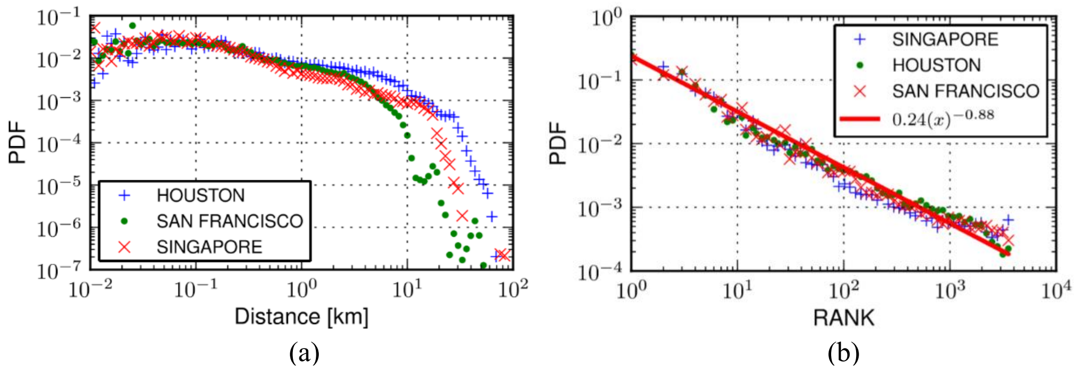


Fig 2.3-2 (a) The probability density function (PDF) of human displacements in three cities: Houston, San Francisco and Singapore; (b) Probability density function (PDF) of rank values for three cities: Houston, Singapore and San Francisco (Number of intermediary sites between two sites) (Liu Y et al., 2012)

Among them, mobility is the most direct external manifestation of individual hierarchical spatial behavior. For individual mobility, the probability of long-distance travel is lower and that of short-distance travel is higher because of distance attenuation effect. Functions that characterize this distribution include power law distribution, exponential distribution, exponential truncated power law distribution, etc. [53, 96, 97] In addition, human mobility patterns are also influenced by geographical environment and intermediary opportunities. Urban mobility is influenced by the structure of urban land use. Usually, the intensity of land development in urban central area is relatively high and the travel density is relatively high, while in urban remote areas, the intensity of land use and travel density are relatively low.[98]

Noulas used Foursquare check-in data from many big cities around the world to study the regularity of human movement patterns in cities. They find that there are differences in the distribution of human movement steps in different cities, which are influenced by the distribution density of places in urban geographic environment. If the number of intermediary sites is used to measure distance, the universal power decay characteristics can be found in all cities. (Fig 2.3-2)

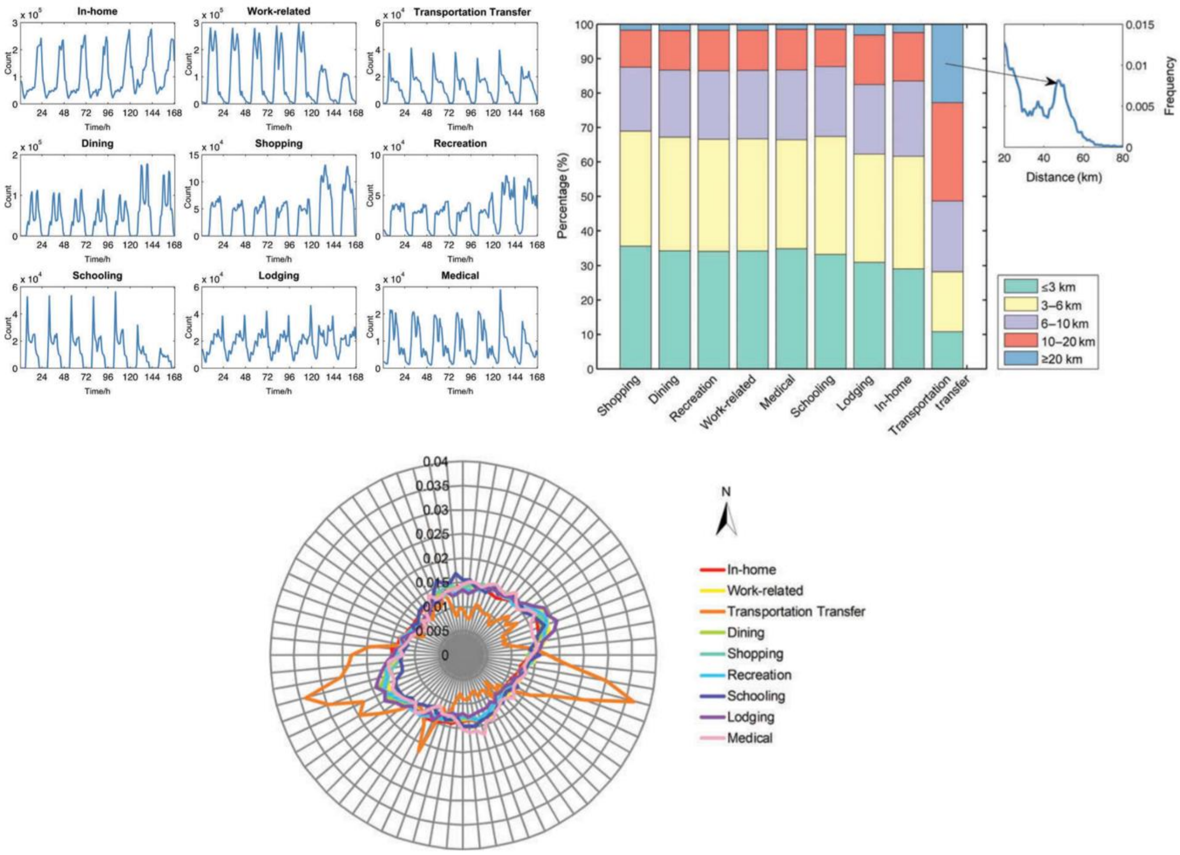


Fig 2.3-3 Spatio-temporal features for nine types of daily human activity (Gong et al., 2016)

The big geo-data with abundant trajectories often has the disadvantage of inadequate activity information, which makes the rich semantic information behind the trajectory (especially the travel purpose information) missing. In the study of traffic geography, the purpose of travel is to understand the basis of the mode of travel movement, and different purposes of travel are subject to different spatial constraints. Some scholars try to deduce the purpose of trajectory and enrich the semantics of trajectory by combining trajectory data, time constraints and geographical environment characteristics, so as to better understand the activities of urban residents.

Gong et al. (Fig 2.3-3) combined rich POI data with semantically missing taxi trajectory data, put forward a research framework to infer taxi passenger's travel purpose, and based on the inference results, revealed the spatial and temporal dynamic characteristics of nine basic types of daily activities in the city, including time-varying regularity and spatial distribution dynamic characteristics.[99]

b. Sensing of regional dynamic activities and linkages

The dynamic activities and population distribution at the regional scale in cities can be revealed by aggregating the dynamic characteristics of individuals in multi-source large data. Time markers in big data can be used to explain the dynamic characteristics of population distribution, while spatial markers can encode the geographical location of individuals into the corresponding plots or regions to achieve human-to-earth perception.

Yuan et al. inferred the function of land masses by using human movement data between urban land masses and POI data within the area. Regarding land as a document, land function as the theme of the document, POI classification as the metadata of the document, and space-time movement information of human beings entering and leaving the land as the word of the document, the urban land can be automatically classified based on the theme function.[100] Based on the hypothesis that urban spatial structure will affect people's daily public transport travel, Zhong et al. used Singapore's public transport card swipe data from 2010 to 2012 to detect the evolution of urban structure.[94] (Fig 2.3-4)

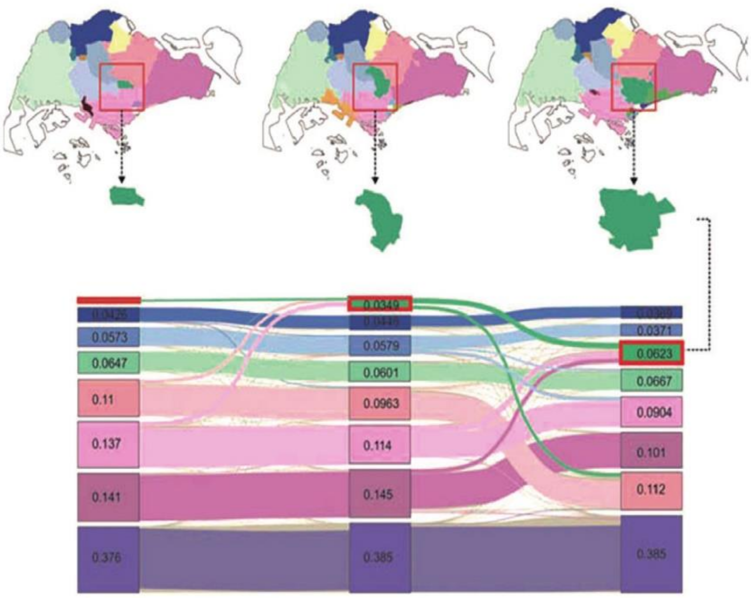


Fig 2.3-4 Evolution of community structures in Singapore using smart card data from 2010 to 2012 (Zhong et al., 2014)

c. the emotional and semantic sensing of place

Multimedia data in social media data has become an important source of semantic information acquisition in large data research. Located social media data usually accounts for 3%, which researchers can use to reveal semantic information related to geographical location. At present, the study of perceptual place semantics mainly includes the following three aspects: (a) Obtain the evaluation indicators or themes of a place;[101] (b) Obtain emotional information related to the place, such as happiness or depression;[102] (c) Response to hot events, such as disasters, diseases and accidents[91].

In recent years, with the development of image recognition and in-depth learning technology, it is possible to automatically extract semantic information from photos and apply it to place perception. Combining with traditional text analysis, rich semantic information can reveal the characteristics of geographical environment more objectively and completely, and capture the experience brought by places. Zhou et al. used more than two million geographic location-marked images from 21 cities in three continents in US to extract seven characteristic attributes (greening degree, water coverage, transportation, architecture, high-rise buildings, sports, social activities) of the city by in-depth learning, so as to capture the city's spatial distribution of image dynamically.

4. Limitations and possible improvement

The emergence of big geo-data has brought tremendous progress to the traditional urban research and planning practice. More accurate empirical studies are emerging, which makes the framework of urban research more perfect. However, at present, the research work of using large geographic data to perceive Urban Dynamics still remains on how to improve the model integrity, accuracy of results, calculation efficiency and so on. The large data used is pre-collected and stored, and can only be regarded as semi-dynamic 'static' work.

From review of the above limitations of the application of big data, the development of the application of big geo-data should be carried out from the following aspects: a. From the aspects of model integrity, result accuracy and computational efficiency, the use of artificial intelligence technology will make further progress in this kind of research; b. At the level of real-time application, a city dynamic perception system is constructed, and real-time data is fully used for city detection and monitoring, providing solutions for real-time problems; c. To guide the planning and design practice, refine the use of large data, especially in the renewal and transformation of urban built-up areas and activities planning, the use of large data to fully assess the built environment from the pure form of parametric design to empirical, quantitative and objective data-based design.

2.4 Literature Review about Leading Research of Streets that Using Big Data

In research about streets, there are several leading fields where big data is used. Among the many kinds of researches, three of them which are strongly related with this dissertation are listed and analyzed here to support: a. space syntax; b. walk score; c. pictorial urbanism. Thesis basis; main methods used; shortcomings and possible improvement are supplied in each field.

1. Space Syntax

Space syntax has great reference value for this study. On the one hand, the topological model adopted by space syntax is a classical structural model of urban outer space, which is of great reference significance. This study will also use this model to translate street structure. On the other hand, unlike traditional spatial syntax research, urban land use is different. The influence of cloth and other attractive factors on urban network is gradually being considered by space syntax.

Space syntax, as a theory and model of architecture and urbanism based on spatial topological connection to study user behavior, originated in the 1980s. [104] Space syntax is a series of theories and techniques about space and society. Its core idea is that space is not the background of social and economic activities, but a part of social and economic activities. The space referred to in spatial syntax is not only the object described by Euclidean geometry that can be measured by mathematical methods, but also the relationship between spaces such as topology, geometry and actual distance. It not only pays attention to the local spatial accessibility, but also emphasizes the overall spatial accessibility and relevance.

Specifically, in the research of spatial distribution of active functions, early achievements on urban commerce mostly focused on shop agglomeration, focusing on the connection between the streets of commercial agglomeration and the whole city and its surrounding districts, and less on detailed quantitative analysis related to the types of specific functional formats and the use of residents. Even the early scholars of spatial syntax think that it is enough to study the human behavior pattern from the perspective of simple street network connection, without further consideration of land use relationship and usage.[104] This is also the reason why the study of spacel syntax has been criticized.[105]

Space syntax has tremendous potential for development and application because it considers all elements such as cost of arrival within the scope of calculation. It also has strong reference value. On the theoretical level, Marcus, L. and others believe that space syntax has universal value and can be further developed for the study of invisible urban network structure, for example, economic, social or cultural networks;[106] In practice, Ståhle, A used spatial syntactic models to calculate the cumulative activity opportunities in geometric buffer by using GIS.[107] Qiang. S, Zhensheng. Y and others use spatial syntactic model as the main analysis tool and use network data to quantitatively analyze business distribution and aggregation at multiple scales. These studies show that they can make full use of the mature structure model and calculation principle of space syntax and make quantitative research with current data.[108]

In application of space syntax in studying function/ function connectivity of streets, Street Vitality Research is always the Focus of Urban Planning Research. For example, Ying. L. and Yao. Sh. took the lead in proposing Street Urbanism[109], and quantitatively explored the street vitality on a large scale and a fine scale, using multi-source data to measure and analyze the street vitality in Beijing's Fifth Ring Road, and Pei Yu used similar methods to analyze the night street in Beijing's Second Ring Road. Analysis of Tao Vitality and Influencing Factors.

2. Walk Score

The significant effect of walking on urban sustainability has attracted worldwide attention. More and more walkability evaluation studies have been conducted in recent years. Walking is the instinct and need of human beings. It is the healthiest and the most low-carbon way to travel. Promoting pedestrian concept and encouraging pedestrian-friendly Street development can bring many benefits to urban residents and urban development itself.[110]

Walkability is a spatial attribute, which describes the guiding ability of space for people's walking trip. It refers specifically to the spatial proximity between the starting point and the destination and the convenience and comfort of walking between two points.[111] Walking index is generally recognized to affect pedestrian activities. Some studies take plots or blocks as research units. By calculating walking index through factors such as residential density, volume ratio, density of road intersections and land mixing degree, the paper tries to analyze the relationship between walking and income level [112]; walking and air quality [113]; and walking and pedestrian activities [114].

There are many evaluation methods of walking index, the most direct method is to count the number of pedestrians and their activities.[115] Reid Ewing observes human activities through video clips of street scenes and expert ratings, and evaluates the impact of urban imagery, enclosure, human dimension, perspective, complexity, recognition, continuity and consistency on walking behavior.[116,117] Observed or monitored human flow and population density are objective, but they can not reflect the purpose and type of pedestrian activities, can not identify the enthusiasm of activities, and the cost is high, which means it is necessary to explore a quantitative evaluation method of street walkability, and provide a set of unified measurement indicators and calculation methods for longitudinal comparison between different streets and cities.

At present, there are two main research directions in the measurement of walkability: one focuses on the function of streets (or blocks), that is, the purpose of walking here [119]; the other is considering the design of the street, which means the necessity to walk in a pleasant and safe environment.[120,121] In 2007, American researchers put forward the concept of "Walk Score" based on the layout of daily facilities, which mainly considers the types and spatial layout of daily facilities. At the same time, some factors such as walking distance attenuation, intersection density and block length are introduced to improve the accuracy of measurement. It is the only international quantitative method to measure the walkability, and has been widely used in the United States, Canada, Australia and other countries.

Walk Score is a typical function-oriented computing method, which considers the connectivity of streets, but ignores the street environment. [122] This perception may have a complex or subtle relationship with the physical environment characteristics, thus promoting or reducing walking ability, thus leading to a certain deviation in the results. In the practical application of walking index, some results can not be confirmed because of certain factors or specific areas. For example, the study in Las Vegas shows that there is no relationship between walking index and land value.[123]

3. Pictorial Urbanism

With easy accessibility and processing technique of images, Ying. L. and Yin. Zh. proposed that images are an important supplement to urban data resources, and raised the concept of pictorial urbanism as a subject-object method of urban study.[124] In the new data environment, pictures occupy a large proportion, especially a large number of pictures with spatial location become an effective source of describing urban physical space and social space. Other new data are mostly represented by numbers. If they are called table-valued data, then the more complex, higher-dimensional and abstract data represented by images and languages can be called "ideographic data". The former is convenient and efficient in data processing, while the latter more reflects the richness and complexity of information. Because of the difficulty of the analysis of "ideographic data", more research has been done in the field of computer, while less research has been done in the field of city. At the same time, image processing technology is becoming more and more mature. Application Programming Interface (API) provided by many websites reduces the difficulty of image analysis.

Compared with traditional data with only point information or text attributes, image data with spatial location has the following advantages: a. There is a large amount of information and pictures contain a lot of content. Pictures reflect the size, shape, composition, function, style, quality and sense of place of material space, and also reflect the density, vitality, spirit, stratum and happiness of social space. Pictures can be further excavated and analyzed from different directions; b. Convenient communication, no barriers to language differences, facilitating comparative studies in different regions of the world; c. Pictures are intuitive and easy to establish links with the space environment.

Information mining with spatial location images can be divided into the following three categories: image metadata mining (such as location, time, etc.), image text label mining and image content analysis.

The most common way to use image metadata is the analysis of tourism hotspot areas and urban morphology. For example, Eric Fischer used Flickr photo point data to map the urban form of more than 100 cities in the United States, Canada and Europe, and to distinguish the spatial distribution of local residents and tourists. Tammet developed Sightsmap based on the point density of Panoramio photos, showing the distribution of the hottest landscape in the world.[125] Photo metadata and text label information are also commonly used in travel route recommendation and crowd spatial-temporal behavior analysis. For example, Gavric et al. analyzed Berlin's tourist hotspots and tourist routes based on Flickr data.[126] Palomares et al. studied the spatial distribution of tourism hotspots in eight big cities in Europe based on Panoramio images. Based on the spatial statistical analysis function of GIS, the spatial differentiation rules of local residents and foreign tourists were analyzed. The results show that the spatial concentration of foreign tourists is higher in Barcelona and Rome than that of London and Paris.[127]

2.5 Summary

To sum up, from the perspective of street function, the development of street function shows that the connotation of street is rich in three levels: passage way, compound functions and social value; the research means show that the research on street is rich in angles and means, and there is a trend towards the application of big data; but the understanding of street function from the perspective of time flow consciousness, it is found that the academia has a consensus on functional changes, but lacks quantitative means.

There are many factors that are influencing functional changing of streets according to previous literatures. Four dimensions of motivations can be summarized as people, activities, physical environment and social environment. Besides, the understanding of the motivations should not be limited in city view but be expanded from people's perspective.

From the point of view of media big data and its comprehensive application, it is found that the research of human space activities is the most popular application direction of big geo data; big geo data itself has obvious defects, but can be remedied by other data; at present, big geo data, like many other types of large data, is still used for semi-dynamic 'static' work, which has the potential of dynamic research progress.

To understand city from dynamic view, topological structure model from space syntax can be used, as from the perspective of spatial syntax and its research, it is found that, as the most classical study of streets, the application of spatial syntax has also begun to focus on functions. At the same time, the topological structure model established by spatial syntax has universality and great application value. Additionally, thesis from WalkScore and pictorial urbanism can also help the understanding of city from dynamic terms for their consideration of people's behavior.

Chapter 3 Methodology

3.1 Definition of ‘Function of Streets’

1. What is ‘function of streets’

The object of this research is streets, from the perspective of functional changing. Hence, it is analyzed firstly what is ‘function of streets’.

The existence of streets is first embodied in the traffic function. It is necessary to provide people with access to travel and meet people's basic daily needs, such as going to work, going to school, shopping, waiting for the bus, etc. Secondly, streets should bear certain additional functions, arrange various commercial and service facilities, as a "market" form, to meet the residents' catering and trading needs. Thirdly, the streets must be equipped with various municipal infrastructure, such as power communication pipelines, water supply and drainage pipelines, natural gas supply pipelines, heat supply pipelines and so on.

These three basic functions which are ‘visible’ are defined in previous literature reviews as ‘function of path’ and ‘compound function’. According to the classical works of related with streets and the researched of related scholars, function of streets can be also ‘invisible’ in terms of connecting different ‘visible’ functions, connecting urban tissues, or even connecting social network.

In this research, it is considered that people’s usage of streets is making the function of streets changing with time and people’s usage by accepting products and services or by occupying the space along the streets. It is also supposed that the capacity of traffic volume of streets stays unchanged all the time. Based on this view, this research is defining ‘function of streets’ from a limited sense as well as in general terms.

From limited sense, this research has narrowed the ‘function of streets’ into functions that provide products or quick services to users using the physical space of streets, which are visible, which means services like schools, hotels are excluded for they are often not strongly street-based. In general terms, ‘function of streets’ is defined as the connectivity of the network system of streets in integrating ‘functions’ defined in limited sense, which are invisible in physical space.

2. Connection and difference between functional changing pattern and vibrancy of streets

a. Connection between functional changing and vibrancy of streets

Vibrancy of streets drives the functional changing process. On the one hand, when activities in some specific spaces in the city increase, which is considered as vibrancy, it means more people using the space and more opportunities of mixed functions in surrounding area including streets. On the other hand, activities of citizens’ moving are conveyed through connections between different functioning areas, which are streets. With the increase of activities, the connections become stronger. Hence functional changing and vibrancy of streets are strongly correlated with each other. Additionally, both functional changing and vibrancy of streets can be measured through people's usage.

b. Difference between functional changing and vibrancy of streets

Although there are similarities between these two concepts, differences are still manifest to discover. Firstly, function of streets do not disappear because of the loss of vibrancy. When people talking about 'vibrancy', it is always based on activities happening on street, based on people. However, vibrancy is only a status of streets, when many people are using the streets, the street will be evaluated as 'high vibrancy', when few people are using, the street will be evaluated as 'low vibrancy', or 'no vibrancy'. Hence, in most researches that studying the vibrancy of street, 'people' is used as an indicator of measuring vibrancy, and the vibrancy is usually shown as 'high' or 'low', for the purpose of discovering its correlation with elements of urban physical environment. Secondly, although both functional changing and vibrancy can be measured through people's usage, they emphasize different sides: for vibrancy, indicators of number of people, mixture of functions and people are often sum up into 'vibrancy', whereas in functional changing, how people are using the space will be more important, and for the streets of same level of 'vibrancy', the functional changing mode can be very different. Thirdly, in terms of researching area, 'vibrancy' work better in city level in that from city center to periphery, vibrancy vary lot according to agglomeration effect; functional changing makes more sense in intermediate and micro perspective for in this scale, the whole area is usually under similar level of vibrancy, comparing vibrancy again in this case will not make much sense.

3.2 Description of Research Problem and Main Hypothesis

This research is making hypothesis of two parts, first is about the functional changing patterns of selected streets; second is about the drivers of the temporal and spatial changing patterns.

1. What is the temporal and spatial changing pattern of urban street function?

In this part, two aspects of outcomes and conclusions are preset based on clustering as follows:

a. Concluding functional changing pattern from a limited sense:

Describing how the function of street in limited sense change with time of the day. This process is realized through clustering streets by functions. Comparisons lie in (a) how different kinds of function change with time, when they are activated, when they disappear, what is the leading function; (b) the dynamic pattern of two streets areas, their similarities and differences; (c) functional patterns of the whole areas during the week and weekend, their similarities and differences.

b. Concluding functional changing pattern in general terms:

Describing how the function of street in general terms (functional connectivity) change with time of the day. This process is realized though clustering streets by connectivity of different time periods. Comparisons are about: (a) how street connectivity change with times, specifically in density, diversity and delivery; (b) how street connectivity change with different radius, specifically within each street, within radius of 300m, and within radius of 500m; (c) the dynamic pattern of two streets areas, their similarities and differences.

2. What is the motivation of functional changing patterns?

In this part, motivations are analyzed not only in qualitative terms but also in quantitative ways.

a. Qualitative analysis:

Qualitative analysis is used to discover the difference between functional changing pattern of two study areas, preset result include: (1) general difference: The selected commercial districts have different shapes, one in planar and one in lineal; different locations, one neighboring center and the other distant from the center; different scales, one larger and the other medium; although they all include leisure, entertainment, catering and shopping, their consumption levels are also different; (2) historic difference: from the view of land use transformation, one in preservation of historic core; and the other in consolidation of CBD; (3) policy difference: the traffic policy that divide the Milan city into area B and area C.

b. Quantitative analysis:

The quantitative analysis is based on the result of clustering in functional changing patterns of streets. The main hypothesis is that streets clustered into the same group are of high socio – economic – environmental similarities. The preset results are that: (1) socio aspect: factors of ‘people’ domain are affecting functional changing patterns of streets; (2) economic aspect: factors of ‘activities’ domain are affecting functional changing patterns of streets; (3) environmental aspect: factors of ‘physical environment’ and ‘social environment’ domains are affecting functional changing patterns of streets.

3.3 Feasibility Analysis

1. Research feasibility

The research has strong feasibility:

a) Street space, as an important part of the external space of buildings, has always been the focus of urban planning scholars and planning practitioners. Whether in classical urban planning works or in recent studies, many scholars have done quantity of researches on the spatial function and functional connection of streets. The research methods used include traditional methods of theoretical analysis, field investigation and traditional quantitative analysis; and big data analysis recently and so on. These diverse methods, producing rich research results, have provided strong support for the development of this research.

b) Data involved in the study is available and easily accessible. At the same time, the research is based on the exchange project in Milan, Italy, the author can easily obtain the relevant data of Milan city, do field research in study area, as well as acquire the relevant literature, documents and other first-hand information. At the same time, the researcher can actively communicate with local students and teachers of relevant research, which is helpful to the development of the research.

c) In early preparation, detailed technical route planning and analysis methods are studied, forming the basic research logic. At the same time, this kind of research based on multi source data has precedents, which is basically feasible.

Uncertainty of result:

On the one hand, due to technical reasons, the results are not obvious, that is, at the measurement level of functional and functional connections, the threshold value has been relatively reduced compared with the size of the existing studies at the level of urban central areas, but it may still be too large to make the results too general to observe functional changing patterns of streets. On the other hand, there might be unexplained functional changing patterns. For technical reasons, trials have to be made; for unexplained changes, more on-the-spot investigation, literature reference and other ways have to be introduced to find the causes of errors; for evitable errors, adjust on technical route for research has to be made to optimize the research.

2. Research difficulty and possible solutions

First difficulty in this research is related with quantity of available data. At present, the research based on media check-in data is mostly carried out at city scale. This research is carried out at the meso-scale, and there is a great possibility of data shortage and point location migration. Data shortage means the quantity of data is not thick enough to support the division of time period in check-ins which in turn the data will no longer reflect the fact of the use of space; point location migration means that the collected data of POI might be different from real location which make calculation on specific street wrong as a result. These problems will have slight impact on macro-scale research, but when the scale is zoomed into intermediate, they will be significantly enlarged. Additionally, the research is also faced with problem of lacking data in terms of restriction on access to open data. From October in 2018, Twitter has imposed constraints to personal application for developer account, acquiring data via API becomes almost impossible.

Another difficulty in this research is related with quality of data, specifically, usually caused by the habit of people when they check in. On popular networking platform like Twitter or Facebook, it is usual to see check-in location precise to street, square, or district but seldom precise to specific shops or detailed points. On social networking is more based on pictures like Flickr, origins of photos are not limited to users' check-ins, but official licenses as well.

To deal with difficulties mentioned above, conventional method in city-scale research is using multi-day data collection (half a month to a month), to make every POI have data; at the same time, when the information is really lacking, media data of many kinds are combined to solve the problem. In this research, however, less effective data from Twitter, Facebook or Flickr is not used, but combination of Foursquare data and Google Popular Times data is introduced. Foursquare data is based on point of interest, but lacks check-in time information; Google Popular Times aggregated and anonymized data from users who have chosen to store their location information on Google servers.

3.4 Research Areas

The research has selected 2 streets in Milan as research objects: San Babila, Porta Nuova - China Town. Location of the two area in Milan city is shown in Fig 3.4-1 with main transportation lines. Relationship between study area and 9 municipals is shown in Fig 3.4-2. According to Milan Government Plan of the Territory (PGT: piano di governo del territorio), Milan city area is divided into 88 NILs (Nuclei di Identita' Locale[1]). The NIL cards represent a real territorial atlas, a tool for verification and consultation for the programming of services, but above all for the knowledge of the realities of the neighborhoods that make up the different local realities, highlighting unique and different characteristics for each nucleus. Relationship between 2 selected streets and the NIL cards is shown as in Fig 3.4-3.

Fig 3.4-1 location of study area in Milan city

[1] http://www.comune.milano.it/wps/portal/ist/it/servizi/territorio/piano_governo_territorio_vigente/piano_servizi_vigente/pds_nil

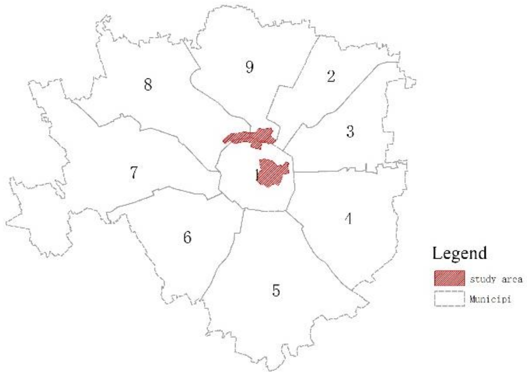


Fig 3.4-2 Relationship between study area and 9 municipals

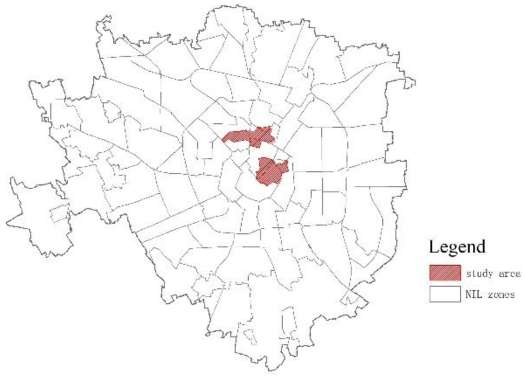


Fig 3.4-3 NIL division and its relationship with study area

According to previous study, these two areas are chosen for the reason that they are at similar level of vibrancy at city level to make the functional changing pattern analysis meaningful. Details of the two selected areas is shown in Fig 3.4-4.

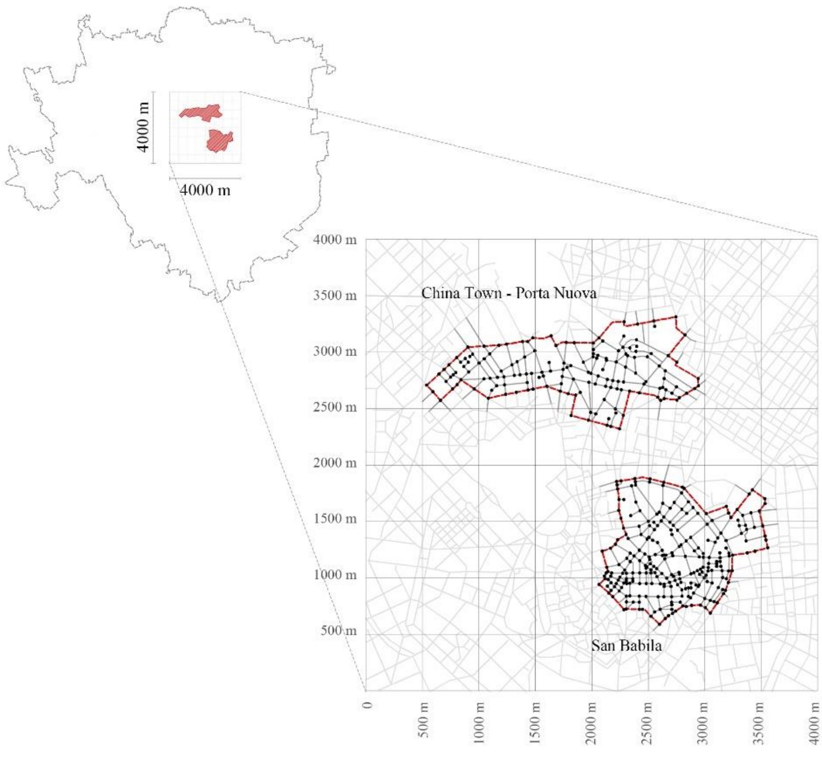


Fig 3.4-4 Details of study area

1. San Babila

San Babila square and its surrounding districts are located in NIL 01. Duomo, including streets Via Montenapoleone, Corso Vittorio Emanuele II, etc. It is in the center of the city of Milan and of the urban region in many ways: services, finance, commerce, culture. However, there are no local services and aggregation opportunities for the resident population. Especially in the evening hours, there are phenomena of petty crime.

Main functions in this commercial area includes leisure, entertainment, catering and shopping, offering many high-street and mid-range brands, making it one of the best places in Milan to shop for young fashion and international labels.

Fig 3.4-5 pictures of San Babila area (source: collected from Internet)

Fig 3.4-5 is trying to give an impression of area San Babila. Made up of different styles of buildings from variety of ages, this area, which is located in the most central part of Milan, is providing people with all kinds of experience when walking inside. Crowded streets from San Babila all the way to Duomo is providing compound services of shopping as well as recreation; whereas high-end shopping places in Quadrilatero della Moda are showing the products in quiet boutiques. When walking in Brera, however, Handcrafts, galleries and museums are forming atmosphere different from commercial areas.

2. China Town - Porta Nuova

Located in NIL 69. Sarpi, Milan's Chinatown, known in Italian as Quartiere Cinese, is the oldest and biggest Chinese district in Italy. This pedestrian district stretches over the central via Paolo Sarpi – considered its main street – and reaches the nearby via Bramante, via Aleardi and via Niccolini, forming a real city within the city.

This vibrant and dynamic area is located just a few steps away from some of the significant venues of Milan such as the picturesque Brera, the historical city center and the futuristic buildings of Porta Nuova district. Milan's Chinese neighborhood is an interesting location for a quiet walk or to look at the typical products displayed at the shiny windows at both sides of the road. Its pedestrian paths with cobblestone pavements and its three-storey houses give the area a retro allure, though featuring a strong Eastern personality thanks to traditional Chinese ornaments. Christmas, Chinese New Year and the Oriental Design Week offer one on the liveliest atmospheres packed with events and are the best times to admire a triumph of lantern lighting and decorative elements (Fig 3.4-6).

Fig 3.4-6 pictures of China Town area (source: collected from Internet)

Although same with deep cultural- historic base, this area is different from San Babila in extreme vibrancy in local business and less accumulation of people during most time of the day.

Located in NIL 09. Garibaldi Repubblica, Porta Nuova area is a new exclusive space and one of Lombardy's latest and most innovative economic and business hubs. The district offers different possibilities for free time.

Unlike area San Babila and its connected area of China Town, Porta Nuova is distinguished by its modern style of buildings with big open spaces, which symbolizes new Milan. Many new landmarks of Milan can be observed when walking in this area, including UniCredit, Bosco Verticale, Diamond Tower, and modern residential buildings.

Fig 3.4-7 pictures of Porta Nuova area (source: collected from Internet)

Within the area, Piazza Gae Aulenti, the 'heart' of Porta Nuova is surrounded by arcades hosting the shop windows of numerous upmarket boutiques. Extending northwards towards Milan's Stazione Garibaldi, together with Porta Nuova, district Isola has gradually become a magnet for young creatives and those in search of cool entertainment in the city. Corso Como is the trendy pedestrian area situated between Piazza Gae Aulenti and Piazza XXV Aprile, it's one of Milan's hippest nightlife districts but not only. It also has a great daytime vibe with a fab offering of boutiques, restaurants, pizzerias and snack bars.

These two districts are linked together as one study area not only because they are geographically very close to each other (only 300m connection), but they share same developing trajectory as consolidation of CBD from 1964 to 2018 through history, connecting Milan Central Station and City Life.

Main functions in this commercial area includes leisure, entertainment, catering and shopping. The new transformations bring functional abundance and social mix, which is different from commercial forms in San Babila.

3.5 Data Collection and Management

In this research, data from mainly 3 sources is used, including OpenStreetMap (OSM), Google popular times and Foursquare; other sources of data are also used as supplementation.

1. Open street map

OpenStreetMap (OSM) is a collaborative project to create a free editable map of the world. Rather than the map itself, the data generated by the project is considered its primary output. The creation and growth of OSM has been motivated by restrictions on use or availability of map information across much of the world, and the advent of inexpensive portable satellite navigation devices. The data from OSM is available for use in both traditional applications, like its usage by Facebook, Craigslist, OsmAnd, Geocaching, MapQuest Open, JMP statistical software, and Foursquare to replace Google Maps, and more unusual roles like replacing the default data included with GPS receivers. [2]

Two kinds of data are acquired from OSM in this research: data of point of interests (POIs) and data of street network.

a. point of interest:

Data of point of interests are taken from OSM. The POIs are of detailed classification of 12 kinds, among them, POIs of city street furniture like benches, vending machines, telephones, poste boxes, etc. are excluded for these POIs are not functioning like functional points. After selection, 8647 records of POI are reserved. Categories of POIs are summarized into a table as shown in Tab 3.5-1:

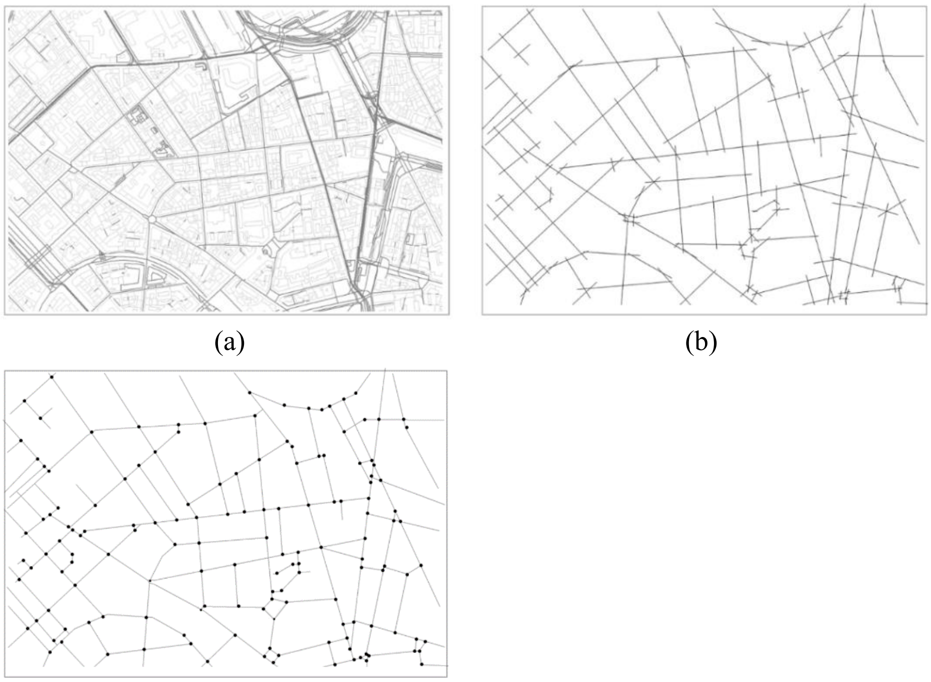
Tab 3.5-1 classification of POI in OSM:

category	**included POI type**
catering	restaurant, café, bakery, beverage, gelato shop
nightlife	bar, night club
shopping	clothes, shoe shop, leather shop, Optical Shop, electronic devices, car dealership, sports shop, supermarket, greengrocery, cosmetic shop, jewelry, toy shop
not clearly defined	butcher, 'do it yourself', florist, laundry, bicycle shop, stationery, bookshop, photocopy shop, hairdresser, beauty shop, giftshop, pet shop, convenience, post office, pharmacy, tabacchi, bank, car rental, community center, culture center, hospital, clinics, fixing shop, veterinary, parking lot
recreation	cinema, theatre, gallery, museum, gym
open spaces	square, park, garden
tourism	historic site, church, viewpoints, travel agency
companies	internet related company, design studio, advertisement, headquarter, other companies
government	government, embassy, institution
accommodation	hotel, hostel, guesthouse, motel
education	kindergarten, primary school, middle school, university
stalls	news agency, florist, kiosk

[2] https://www.openstreetmap.org/

b. street network:

Data of street network are downloaded from the OSM directly through QGIS and Geofabrik. Sample shown below is part of China Town, map data collected through QGIS and Geofabrik is shown as Fig 3.5-1(a), which contains huge quantity of repeated and disruptive lines, contrary to the need of spatial calculation. To deal with the problem, original data is replaced by a 'axis-point model', which shares the same principle with axis map model of space syntax theory. According to space syntax, the axis map model is built to show the trajectory of human movements in urban streets. As humans are not sensitive to every slight directional change in streets, a cut off angle can be given to approximate conditions in streets or nodes of irregular forms (Fig 3.5-1(b)). Finally, this sample area is transformed as axis-point model in Fig 3.5-1(c).



(a) (b) (c)

Fig 3.5-1 original data of OSM street network and its management:
(a) original data collected from OSM; (b) principle of street network transformation in space syntax; (c) result of 'axis-point model'

2. Google 'popular times'

'popular times' is a function proposed by google maps from August of 2018. To help customers plan visits to their business, Google show information including popular times, live visit information, wait times, and typical visit duration. This data appears below regular business information on Google Maps and Search and can help customers plan their visit.

To determine popular times, Google uses aggregated and anonymized data from users who have chosen to store their location information on Google servers. Popular times are based on average popularity over the last several weeks. Popular times, wait times, and visit duration are shown for business if it gets enough visits from these users. People can't manually add this information to their location, and it appears only if Google has sufficient visit data for the business.[3]

According to official website of Google, visit data include (Fig 3.5-2):

Popular times graph: Shows how busy the location typically is during different times. Popularity for any given hour is shown relative to the typical peak popularity for the business for the week.

Live visit data: Shows how active your location is right now which is updated in real time and overlaid on the popular times graph.

Visit duration: Shows how much time customers typically spend at the location. Visit duration estimates are based on patterns of customer visits over the last several weeks.

Wait time estimates: Shows how long a customer would have to wait before receiving service during different times of the day, as well as the peak wait time for each day of the week.

Fig 3.5-2 popular time graph in Google popular times
(Source: https://support.google.com/business/answer/6263531?hl=en)

In this dissertation, to detect functional changing pattern of selected streets, popular time graph is mainly used. Advantages in this source of data is manifested as higher accuracy since it averages data over a period, this means small amount of data can represent long time variation. Compared with traditional check-in data with time information like twitter, Google popular times avoided the problem of check-in preference. Additionally, in small geographic range, twitter lacks check-in density in accurate location to specific shops, which means data is not thick enough to support the research.

However, there are still several limitations in this source of data. Firstly, 'popular times' data as new function has not been available from Google's API for now. Secondly, not all businesses have a popular times graph; the graph will only appear for businesses whose hours are listed on Google and about which Google has sufficient popularity data. Besides businesses lacking visitors, businesses having no data are mainly hotels, companies, schools whose feature is people are not 'visiting' them, but using as destination for long stay; and small stalls in open spaces like vendor's stands, information point. Thirdly, the data shows periodical popularity relative to the typical

3 https://support.google.com/

peak popularity for the business for the week, which means the data shows no absolute check-in amount without the peak value.

For unavailable API, ‘popular times’ data are taken and matched to the selected POIs manually. Collection of data is done twice using data of weeks of March 4th-March 10th and April 1st-April 7th. This time period has avoided festivals and feast days to exclude unnecessary influences. For lacking data issue, businesses lacking visitors are considered as ‘no visitor’ and typical businesses having no data are considered as factors influencing functional changing of streets. On this basis, POIs having google popular time data are considered as ‘activated functional points. For problem of no absolute check-in amount, this research uses other complementary data source as peak value to simulate.

3. Foursquare

Foursquare is a social networking service that provides users with location service, software and games. Users can "check-in" at an actual location by using mobile devices or sending messages. Each time a user reports on a new location, they receive a digital prize or a digital badge as a reward which can be converted into real goods in the future. According to official announcement, Foursquare today has 10 million subscribers (data of 2018), creating average about 3 million check-ins per day. In addition, more than 400,000 businesses have logged on to the Foursquare platform to interact with consumers, and more than 10,000 developers have written applications for Foursquare. Check-ins outside the United States have reached 358 million.[4]

Foursquare offer API for developers to acquire this information. API calls to endpoints can be broken down into two categories: Regular and Premium. Regular API calls only return basic firmographic data, the venue category, and a venue ID. Premium API calls return rich content such as photos, tips, menus, URLs, ratings etc.[5]

In this article, search API is used. After acquisition of venue IDs, a ‘search’ will be applied against venue names, with a limitation of 50 results to return. The study area is divided into 600*600m boxes for the reason that bounding boxes with an area up to approximately only 10,000km^2 are supported.[6]

Foursquare has its own criteria for classifying POIs, categories, included POI types and quantities are shown in Tab 3.5-2 below:

Tab 3.5-2: classification of POI in Foursquare:

category	**included POI type**
Arts & Entertainment	art gallery, aquarium, casino, movie theater, museum, music venue, public art, stadium, theme parks, zoo
College & University	college academic building, medical school, university

[4] https://foursquare.com/
[5] https://developer.foursquare.com/docs/api/endpoints
[6] https://developer.foursquare.com/docs/api/venues/search

Event	market, festival
Food	restaurant, nightclub, brewery, strip club
Outdoor & Recreation	Athletics & Sports, gym, garden, park
Professional & Other Places	Studio, Business Center, Community Center, Event Space, Laboratory, Library, doctors, military base, parking, Post Office, School, Social Club, Spiritual Center, embassy, government
residence	
Shop & Service	bank, dealership, shopping places, bookshop, cosmetic, beauty shop, food and drink shop, sewing, Nail Salon, Optical Shop, Pharmacy, Pharmacy, Sporting Goods Shop, stationery, Tattoo Parlor
Travel & Transport	Airport, station, bus stop, hotel

4. other sources of data

In this research, other open data is also used for further research in discovering motivations of functional changing patterns.

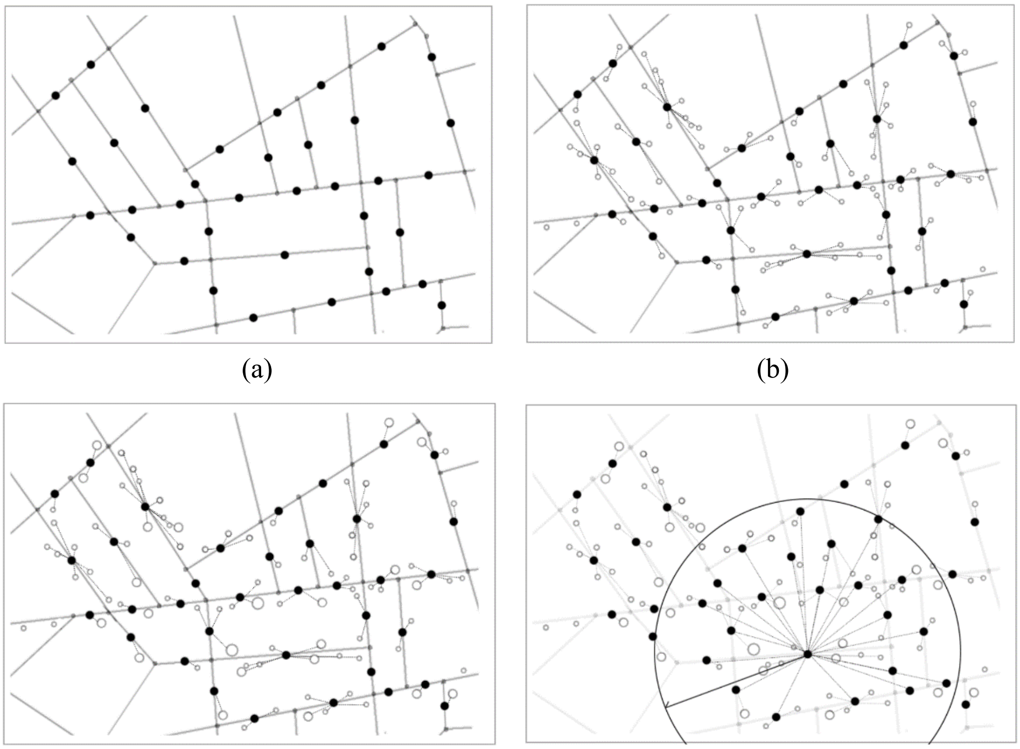
The resources are from open website (http://www.geoportale.regione.lombardia.it/; https://geoportale.comune.milano.it/sit/open-data/), data taken include: detailed geo-data about transportation conditions (public transportations, sharing points, bicycle/ pedestrian lanes, etc.), detailed geo-data about vegetation conditions and land use conditions, etc.

3.6 Preliminary Definition

1. Method for connecting information to streets

In this study, street function is defined as the relatedness information between functional point uses through street networks, representing the sense of function potentials from very street's midpoint to all the reachable functional points. In both narrative and general senses, functional points are the same as POIs, however, for exceptions like cluster of POIs holding same function in a whole area, functional point is defined as centroid of the area with the specific function. 'Street function' is made up by two parts: space function and functional connectivity, both from perspective of and 'usage'.

Land-use system in this essay is conceptualized as a 'path-point model', or 'network interface model' to abstract co-existential relationship between urban functional points and visual paths as graphs. In this model, scored urban function points' locations are assigned to the nearest paths through their spatial interlinkage which is identifies as the interface between buildings and public spaces. By building up linkage between functional points and the streets, activities and information on functional points will be transferred to the interface network at the same time. Locations of functional points and street segments are defined as 'functional nodes' and 'segment nodes' respectively.



(a) (b) (c) (d)

Fig 3.6-1 buildup of network interface model

(a) preprocessed road network and segment nodes; (b) functional nodes are linked with segment nodes; (c) information of functional points are transferred to segment nodes; (d) linkage between different segment nodes within given distance (this research is using distance of walking, which means the range is not a circle finally)

Taking a selected area of China Town- Porta Nuova as example, process mentioned above is interpreted step-by- step in fig 3.6-1 to better understand the model. Firstly, sample data of road network is prepared using principle borrowed from space syntax theory (detailly explained in later chapter) so that segment nodes can be defined; In the following stage, functional nodes are linked to the nearest walking reachable segment nodes, which means to link with the nearest segment node on entrance edge rather than the nearest segment node in space. For some functional points like parks and squares which might taking up a whole district, one functional node can be in correspondence of more than one segment nodes. Notably, scores or any other information can be used to weigh the function nodes to capture the various levels of significance of street functions. In this research, combination of data of 'google popular times' and check-ins from Foursquare is adopted to detect functional changing of 2 streets and to present the diverse types of streets and the proxies for the relative preferences of people in urban destinations. Since street function is defined from aspects of space function and functional connectivity, concept of connectivity between segment nodes in specific range of distance is introduces to measure functional connectivity (function of streets in general terms) only.

2. Defining unit of functional changing

Before the starting of the steps, this research is trying to define how can 24 hours in a day be divided into reasonable number of periods to better conclude the 'changing pattern'. To realize reasonable division, data of Google popular times is used. All the data of functional nodes which are active according to Google popular times are averaged into Fig 3.6-2.

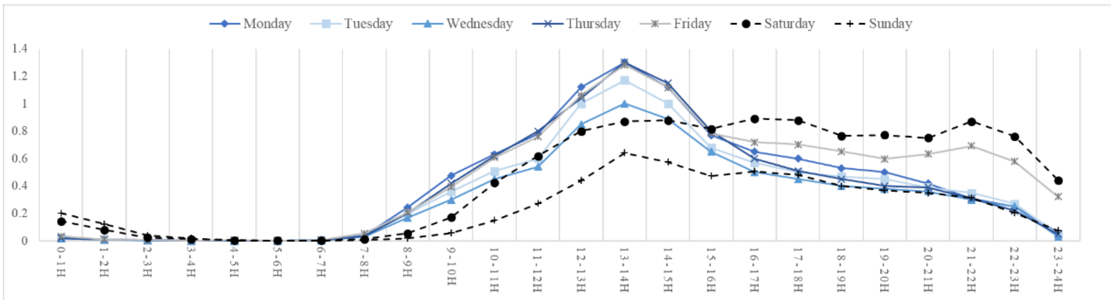


Fig 3.6-2 average value of 'Google popular times'

(Data from weeks of March 4th-March 10th and April 1st-April 7th)

From the graph, it is clear that the mode of Google popular times is showing a recurring pattern. Data for Monday to Thursday is presenting high similarities with data for Monday and Thursday more 'active' whereas data for Tuesday and Wednesday less 'active'. It is quite interesting that data for Friday is sharing same pattern with other weekdays during the day and sharing same pattern with Saturdays during the evening; and data for Sunday is sharing similar trend with Saturday during the day and with weekdays during the evening. Overall, Google popular times data shows more 'active' weekend evenings than weekdays and less 'active' weekend days than weekdays.

This research is dividing 24 hours of a day into every 3 hours based on Google popular times data. From 0th to 3rd hours, decreasing number of people are detected at functional nodes, and the total number stays very low. From 4th to 6th hours, scarcely no people are still at functional nodes. From 7th to 9th hours and from 10th to 12th hours, the city begins to wake up and increasing people are found near functional nodes. Data peaks from 13th to 15th hour, with most people using the functional nodes. Afterwards, data for 16th to 18th hours and 19th to 21st hours witnesses a gentle decrease or fluctuation, which is manifest from the graph. The last 3 hours of the day is presenting sharp decrease and finally recurring to 0th hour. During this process, the 24 hours of a day are split into 8 time period in the following research steps.

3. Defining classification of functional nodes

Another suspending issue is how can different functional nodes be classified into different kinds, which is very important in measuring 'function of street' from narrative view as well as measuring 'diversity' for 'functional connectivity'.

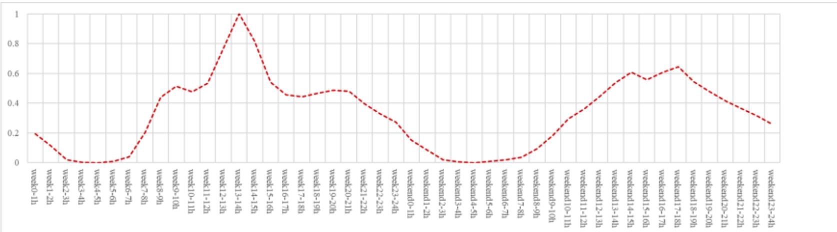
The classifications of functional nodes in OSM, Google popular times, and Foursquare are different, but relative studies in WalkScore have given a principle of classification which is commonly used in many researches. Specifically, 5 categories and 13 types of activity are defined: grocery, shopping, restaurant, bar, nightlife, café, bank, outdoor space, bookshop, school, other recreation. This research combined feature of functional nodes in Google Popular Times and Foursquare to form the classification based on principle of WalkScore. The basic idea is that activities from the same category has similar mode of usage according to Google popular times data. As a result, 10 categories of functional nodes are defined in this dissertation.

Specific categories of functional nodes are shown as follows, with table of specific activities and their category on left and mode of usage graph on right. Red lines show the average usage intensity.

a. Cafés:

Cafés are listed out as a single category based on the reason proposed in WalkScore that from their distribution and serving mode, they are different from other catering services.

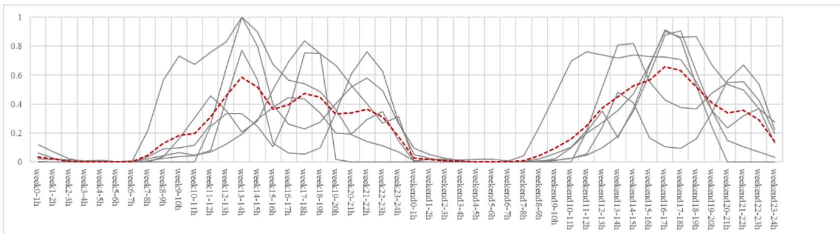
café
café



b. Catering:

Besides traditional restaurants, other shops that provide cooked food and snacks are also included in this type. From the graph, it is clear that functional nodes in this type are more active in weekend than during weekdays.

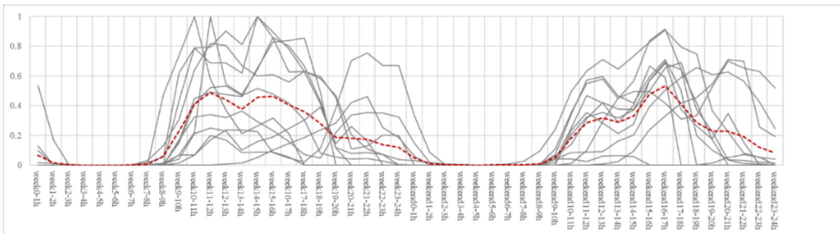
catering
bakery; beverage shops; candy shops; chocolate paces; fast food restaurants; gelato shops; restaurant



c. Culture recreations:

Culture related recreations are about mental layer. Like catering category, they are more active during weekend.

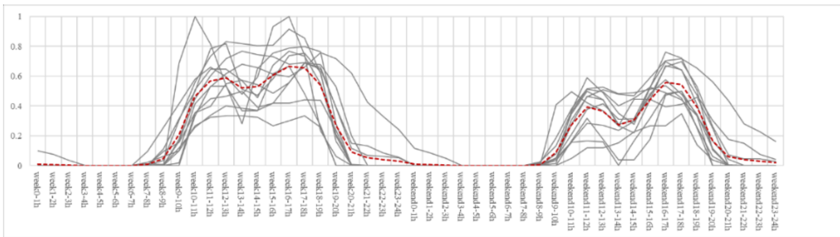
Culture recreations
aquarium; arts centers; attractions; cemeteries cinemas; churches; clubs; exhibitions; galleries; ruins; libraries; museums; theatres;



d. Daily services

Compared with other functional node, activities in this category offer more services than physical products. The usage intensity shows ‘M’ shape during both weekdays and weekend. On average, these functional nodes are less active during weekend because some of them are closed during weekend.

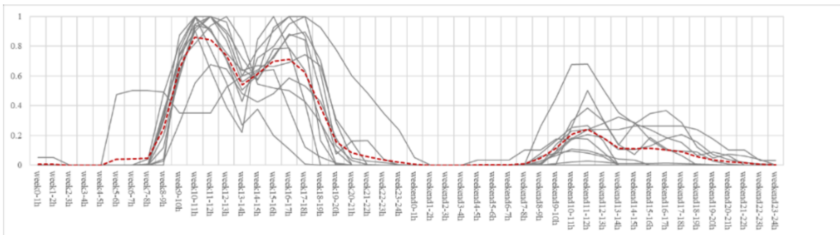
Daily services
bank; car rental; car wash; clinics; dentists; embassy; exchange; fire station; government; laundry; pharmacy; photocopy; post office; veterinary



e. Local shops

Local shops are distinguished from other shops because most of them are run by local people. It is interesting that the average usage intensity of local shops is far active during week than in weekend. It might be for the fact that the open time of local shops are more free than other shops.

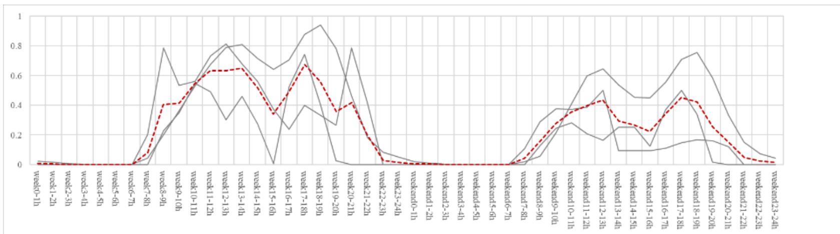
Local shops
antique; art shop; beauty shop; bookshop; casino; convenience; do-it-yourself; electronic; florist; giftshop; hairdresser; music shop; sewing; stationery; tabachhi; tattoo



f. Grocery

Retailers that sell raw materials and semi-finished food. Functional nodes in this category are less active in weekend than during the week.

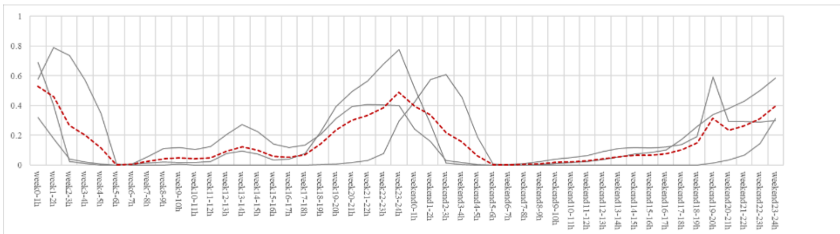
Culture recreations
butcher; greengrocer; supermarket; local markets



g. Night life

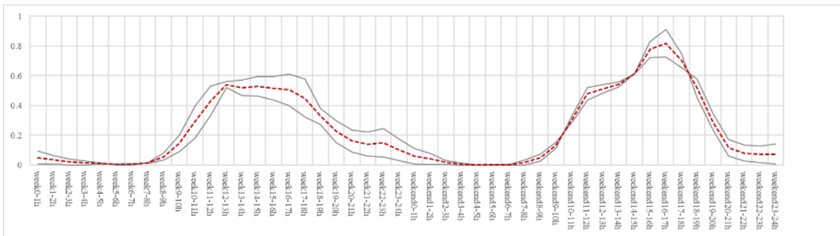
functional nodes in this category are distinguished by the fact that they are far more active during evenings than during the day.

Night lives
bar; nightclub; pubs



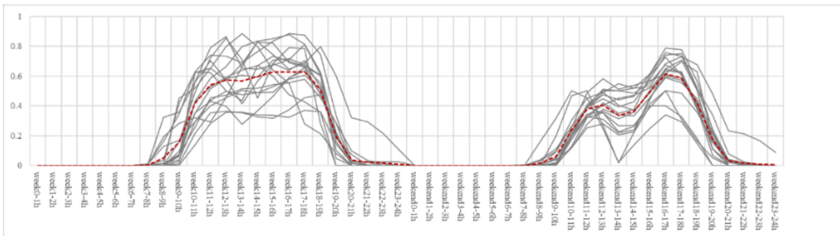
h. Open spaces

In this dissertation, open spaces means functional nodes that are closely linked with streets.

Open spaces	
garden; park; square	

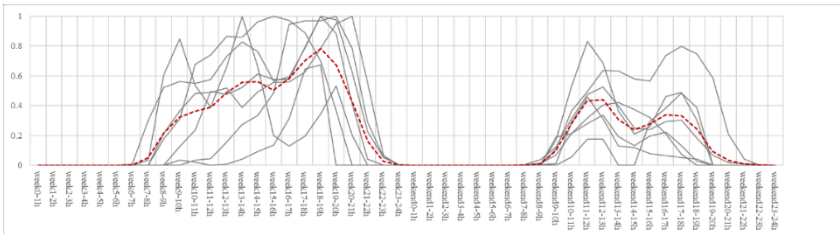
i. Shopping places

Shopping places in this research means retailers selling products of practical supplies. They are chain stores compared with local shops.

Shopping places	
bicycle shop; boutique; car dealership; chemist; clothes; accessory; department store; mall; furniture shop; leather; household; shoe shop; jewelry; outdoor shop; optician; sports shop; toy shop; watch; wine shop	

j. Other recreation

'Other recreation' is relative to 'cultural related recreation' in that functional nodes in this category are more related with physical layer. Included types are related with body health, relaxing and other recreation.

Other recreation	
gym; health center; massage; sports center; swimming pool; yoga studios	

3.7 Research Steps

Main body of the research is made up by two parts, first is discovering functional changing pattern of the selected streets; second is discussion on reasons why the changes happen.

1. framework for discovering functional changing pattern of selected streets

To discover functional changing pattern of streets, this research has introduced a stepwise framework which contains several modules, including data preparation, street characterization and pattern induction (Fig 3.7-1).

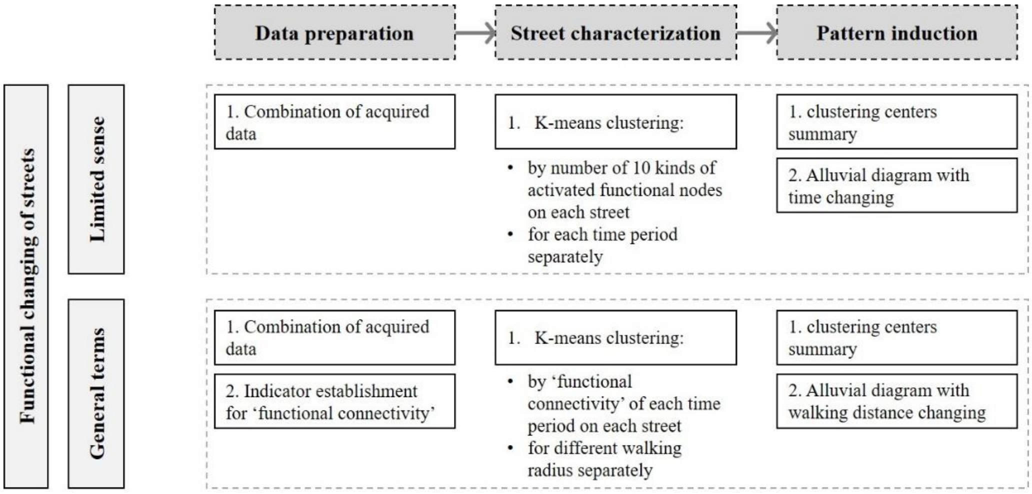


Fig 3.7-1 framework for discovering functional changing pattern of selected streets

In this part, the dataset is processed using a standard GIS procedure. The initial road system is cleared and readjusted according to method mentioned in previous chapter to get a base map that corresponds to visibility and walkability of real streets.

POI dataset is collected and geocoded with the street network. The POIs are then classified as required main type of urban activities as mentioned before. Social media check-in data are linked with POIs based on tags and coordinates after filtering the fake information, such as check-in POI locations outside study area, to get final dataset for calculation which reflects all real usage in real urban space.

(1) Data preparation

The managed data has to be combined and calculated for the process of 'street characterization'. Specifically, this research is combining data from Google popular times and Foursquare check-ins to get the activated functional nodes information and number of users at functional nodes for each time period, which are linked to segment nodes of street afterwards.

For functional changing from limited sense, the data preparation is finished here because 'what is happening on street at specific time period' is unmeasurable. And the characterization is based on activated functional nodes of 10 defined categories.

For functional changing in general terms, functional connectivity is invisible in physical space but measurable. Hence, an indicator system is built up for measuring functional connectivity in terms of 3-D: density, diversity and delivery. Density measures the accumulation of scored activities of the specific segment node; diversity measures the balance degree of all reachable scored activities of the specific segment node; delivery measures how reachable is the segment node of street in the city. This step has chosen the Interval scaling method to normalize the data. Indicators belonging to the same perspective will be normalized, sum up, and normalized again to get the final value of functional connectivity.

(2) Street characterization

This research is trying to characterize streets in terms of changing patterns. Unlike traditional researches from a static view, the addition of dimension 'time' makes streets unmeasurable in terms of 'high' or 'low'. The essence of this research is trying to find out functional changing patterns, discovering which streets are sharing same pattern, which is grouping the streets being studied.

There are many algorithms that can be used in the question of grouping multidimensional data into clusters, among them, hierarchical clustering, two- step clustering and K-means clustering are most popularly used. Other intelligent clustering methods include Nearest neighbor element clustering and self-organized maps (SOM) in neutral network. In this article, K-means clustering is used to group streets. K-means clustering, according to its name, intends to classify group objects into predefined K kinds of clusters where every objective in the same cluster will have the nearest mean.

a. Layers of discussion

K-means clustering is applied to functional changing discovery both from limited sense and in general terms, but the objects of clustering are quite different. (Fig 3.7-2)

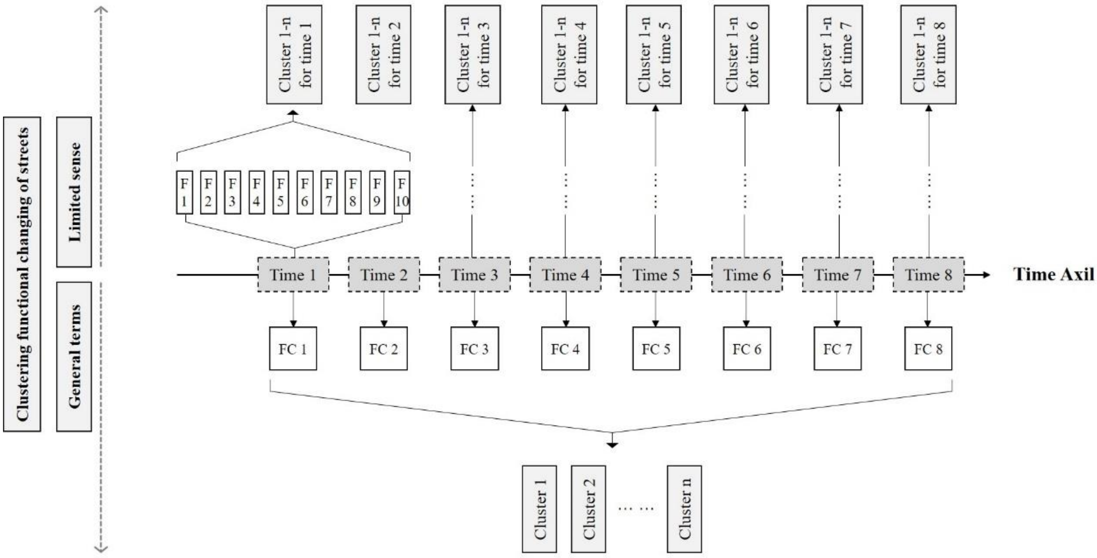


Fig 3.7-2 process of clustering of functional changing patterns (F n = function type n; FC N = functional connectivity of Nth time period; Time N = Nth time period)

For clustering of functional changing patterns from limited sense, the object of clustering is 10 defined functions, which means the clustering is conducted for streets in 8 defined time periods separately. Sample data for clustering is shown in Tab 3.7-1. Before clustering, the data is normalized in comparison with maximum number of activated functional points of the specific functional points category.

Tab 3.7-1 sample data for clustering of functional changing patterns in limited sense:

	F1	**F2**	**F3**	**F4**	**F5**	**F6**	**F7**	**F8**	**F9**	**F10**
	café	**catering**	**culture recreation**	**daily service**	**grocery**	**local shop**	**night life**	**open space**	**shopping place**	**other recreation**
number of activated functional nodes										

For clustering of functional changing patterns in general terms, the object of clustering is functional connectivity of all 8 time periods of streets, which means the clustering is conducted for streets directly. Sample data for clustering is shown in Tab 3.7-2.

Tab 3.7-2 sample data for clustering of functional changing patterns in general terms:

	1st time period	**2nd time period**	**3rd time period**	**4th time period**	**5th time period**	**6th time period**	**7th time period**	**8th time period**
value of functional connectivity								

b. Clustering of streets

Defining number of clusters

Problem of cluster validity has always existed in K-means clustering. Specifically, it is difficult to get evaluation of clustering result and decision of number of clusters before the process is finished.

Elbow method and silhouette coefficient method are the two most presently used method of deciding number of clusters which are experimented as effective. Comparing these two methods used in practical projects, the optimal K value determined by silhouette coefficient method is not necessarily optimal. Sometimes it needs to be selected according to SSE (sum of the squared errors), core index of elbow method, which makes the silhouette coefficient method relatively cumbersome compared with elbow method.

However, this research is combing the two mainstream method because the limitation of data (only 544 streets) might make the 'elbow' unclear in graphs. In combination of the two methods, elbow method is chosen as main criteria when the 'elbow' is clear enough to recognize; whereas when the 'elbow' is not clear enough, silhouette coefficient method is used as supplementary.

Elbow method:

The core index of elbow method is SSE (sum of the squared errors), which can be calculated as follows:

$$\mathrm{SSE} = \sum_{i=1}^{k} \sum_{p \in C_i} | p - m_i |^2$$

Where:

C_i = the i th cluster; p = objectives in C_i ; m_i= centroid of C_i, which is average of all objectives in C_i; SSE = the clustering error of all samples, which represents the clustering effect.

With the increase of clustering number k, the sample division will be more precise, and the clustering degree of each cluster will gradually increase, so the square of error and SSE will naturally become smaller. Moreover, when k is less than the real clustering number, the aggregation degree of each cluster will be greatly increased with the increase of K. When K reaches the real clustering number, the return of aggregation degree will be rapidly reduced with the increase of k, so the decrease of SSE will be sharp, and then become flat with the increase of K value. That is to say, the relationship graph between SSE and K is a shape of the elbow, and the K value corresponding to the elbow is the real clustering number of the data, which is why this method is called the elbow method. The process of SSE calculation can be realized through Python.

Silhouette coefficient method:

The core index of the method is Silhouette Coefficient. The silhouette coefficient of a sample point X_i is defined as $S = \frac{b-a}{\max(a,b)}$, where:

a = the average distance between X_i and other samples in the same cluster, called cohesion; b = the average distance between X_i and all the samples in the nearest cluster, called the degree of separation.

The definition of the nearest cluster is:

$$C_j = \arg\min (C_k) \frac{\sum_{p \in C_k} | p - X_i |^2}{n}$$

Where: p is a sample in a cluster C_k.

In fact, the nearest cluster is chosen as the nearest cluster after the average distance from X_i to all samples of a cluster is used to measure the distance from the point to the cluster. After calculating the silhouette coefficients of all samples, the average silhouette coefficients are obtained by calculating the average values. The range of average contour coefficient is [-1,1], and the closer the sample is within the cluster, the farther the sample is between clusters, the bigger the average silhouette coefficient is, the better the clustering effect is. Naturally, then, the best clustering number is the K with the largest average silhouette coefficient.

Clustering realization

In this essay, process of clustering is realized by SPSS software. To make it happen, all data used for clustering has to be normalized to exclude huge variation in data from different indicators caused by different units.

During the process of clustering, the initial clustering center of each group will be generated by computer in default for the research will not applying any appointed centers for calculation. The automatic clustering process uses random record of data as initial clustering center which means all records have to be in disordered sequence to avoid the result having strong correlation with the order.

SPSS will provide a report about the process and result to better understand how the clustering is happening and what indicators have the statistical significance. Besides result of value of clustering center and number of records that falls into each group, table of iteration history shows the process of iteration until the change of clustering center is approaching 0; ANOVA table gives result of variance analysis, leading to the conclusion of the significance order of the 8 indicators according to F value (the bigger, the more significant). At the same time, a new variable 'QCL_1' will be created in the dataset according to the clustering automatically to help better interpret the result.

(3) Summarizing functional changing patterns

This research is trying to summarize functional changing patterns both vertically and horizontally. Vertically, the summary is mainly based on the result of clustering, both from limited sense and in general terms. Horizontally, the summary is mainly about the difference between the two selected area.

2. Framework for discovering factors that influence the changing pattern

This research is trying to discover factors that influence the changing pattern both qualitatively and quantitatively. A framework of analysis is given as Fig 3.7-3 to make the process of discovering clear.

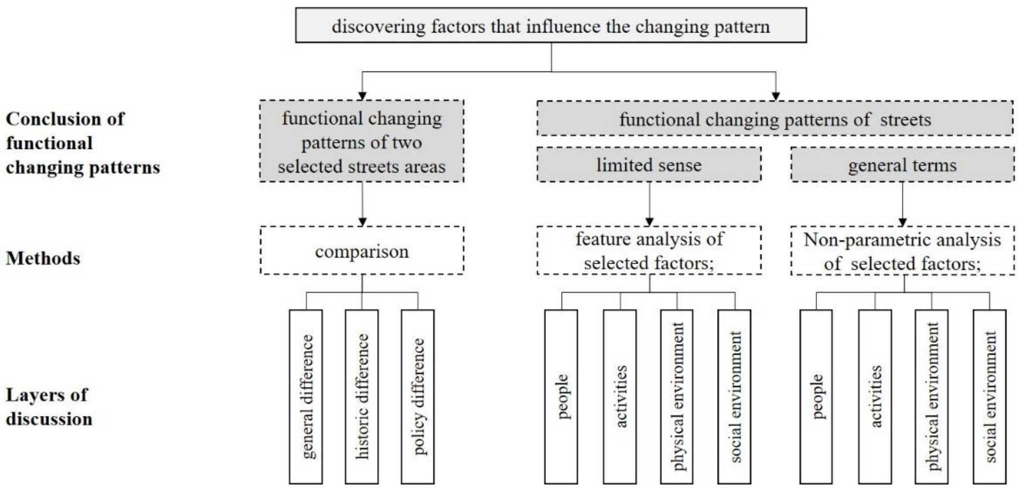


Fig 3.7-3 process of discovering factors that influence the changing pattern

To be specific, the details of the process in discovering factors that influence the changing pattern are demonstrated from perspectives of difference between the two research areas and the difference between clusters of all streets.

(1) Functional changing patterns of two selected areas

In discovering the difference of functional changing patterns of two selected areas, this research is focusing on the general differences between the two area. Method of comparison is chosen for in accordance with the fact that the differences are concluded in qualitative terms.

Comparisons happen from three aspects, that is the general difference of the two areas in scale, in urban space and basic usage in universal cognition; the historic difference by focusing on the land use change during different historic periods; the policy difference by concluding the Milan PGT and the traffic laws.

(2) Functional changing patterns of streets

Discovering the functional changing patterns of streets is focusing on the difference between different clusters after the process of clustering. The essence of the summarizing of different functional changing patterns is groups of streets sharing similar functional changing patterns. This research is making a hypothesis that streets in the same cluster are similar to each other also in terms of factors that influencing functional changing.

The second part of chapter 2 summarized mainstream researches in discovering how people are attracted to products and services of open spaces. Table x. shows all the parameters in chapter 2. These parameters are summarized into 4 domains: people; activity; physical environment and social environment. Factors and indicators are also given to measure the 4 domains. According to the accessibility of data and method, this dissertation is selecting some of the indicators that are measurable to validate factors that are influencing functional changing patterns. Table 3.7-3 summarized factors from chapter 2 that can influence functional changing with indicators.

Tab 3.7-3 factors that can influence functional changing:

Domains	factors	indicators
people	local people/ outsiders/ travelers	--
activities	Mixed function intensity	--
	Business Ratio	--
	Accessibility of daily services	--
physical environment	land use	--
	transportation	Traffic mode; Station Connection; Pedestrian-vehicle balance;
	urban form	Interface density; Wiring rate; Alignment of buildings; Sky view factor, SVF; Sky exposure plane;
	spatial cognition	D/H; W/D; Green vision ratio; Interface openness; Visual Entropy, VE;

	environmental behavior	Transparency of interface; Interface openness; Density of stores; Signage density; Percentage of grey space; Street furniture;
Social environment	inclusivity	--
	safety	--
	landmarks	--

This research is selecting representative factors from Table 3.7-3 to validate the influences. During the validation, quantitative methods are applied to research difference between clusters.

For functional changing patterns from limited sense, the features of the calculated factors will be discussed for the reason that the streets are grouped for each time period separately. For functional changing patterns in general terms, non- parametric tests will be applied to see if the difference between calculated factors of different clusters are manifest.

Traditional way to test whether the two normal distributions have the same mean, t test is often used, which is known as parametric test. The hypothesis of parametric test is that the data is of normal distribution, which is very scare in real case because of lack of enough information about distribution of data; or data distribution far from normal distribution; or measurement of data in sequential variables or nominal variables; etc. In these cases, application of parametric test usually leads to result that is unsatisfying.

The non-parametric tests used in this dissertation non-parametric test of multiple independent samples. Multiple independent samples problems are usually related with testing if different methods, decisions and disposals lead to the same result; like in this research, the problem being tested is about if streets of different functional changing patterns also different in proposed factors.

The process of testing is realized by SPSS in this dissertation. The principle applied is a method like Wilcoxon rank sum test proposed by Kruskal and Wallis in 1952, called Kruskal-Wallis H test. Kruskal-Wallis H test (sometimes called rank-based one-way ANOVA) is a rank-based nonparametric test to test whether there are differences in continuous or ordered variables between groups. There are three hypothesis when applying Kruskal-Wallis H test: firstly, there is a dependent variable, and the dependent variable is a continuous variable or a hierarchical variable; secondly, there are multiple groups (≥2); thirdly, there are mutually independent observations and there is no interaction.

The report offered by SPSS is made up of mainly three parts where the explanation is based. First is Hypothesis Test Summary which summarizes if the difference between groups is significant; second is Independent-Samples Kruskal-Wallis Test which shows the median and distribution of the variable in each group; third is Pairwise Comparisons which shows which groups are significantly different using Pairwise Comparisons of

Physical Activity Level Graph. In the graph, the number next to the point represents the average rank of the group. Connection lines represent the results of comparisons between two groups, black connection lines represent the difference between the two groups is not statistically meaningful, and orange connection lines represent the difference between the two groups is statistically meaningful.

Chapter 4 Functional Changing Pattern from Limited Sense

4.1 Feature of Pre-processed Data

1. Activated functional points

10 kinds of functional nodes are defined in this research in Chapter 2. The activated functional points are intersection of both activated functional nodes in 'Google popular times' data and Foursquare check-in data. The distribution of the activated functional points in space is shown as Fig 4.1-1

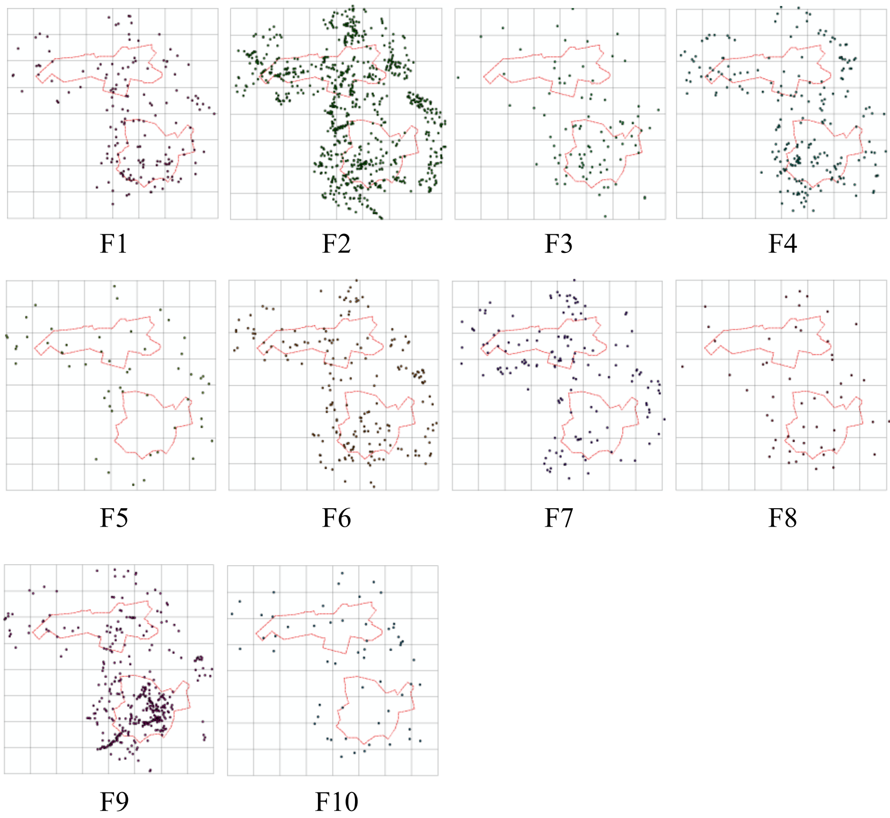


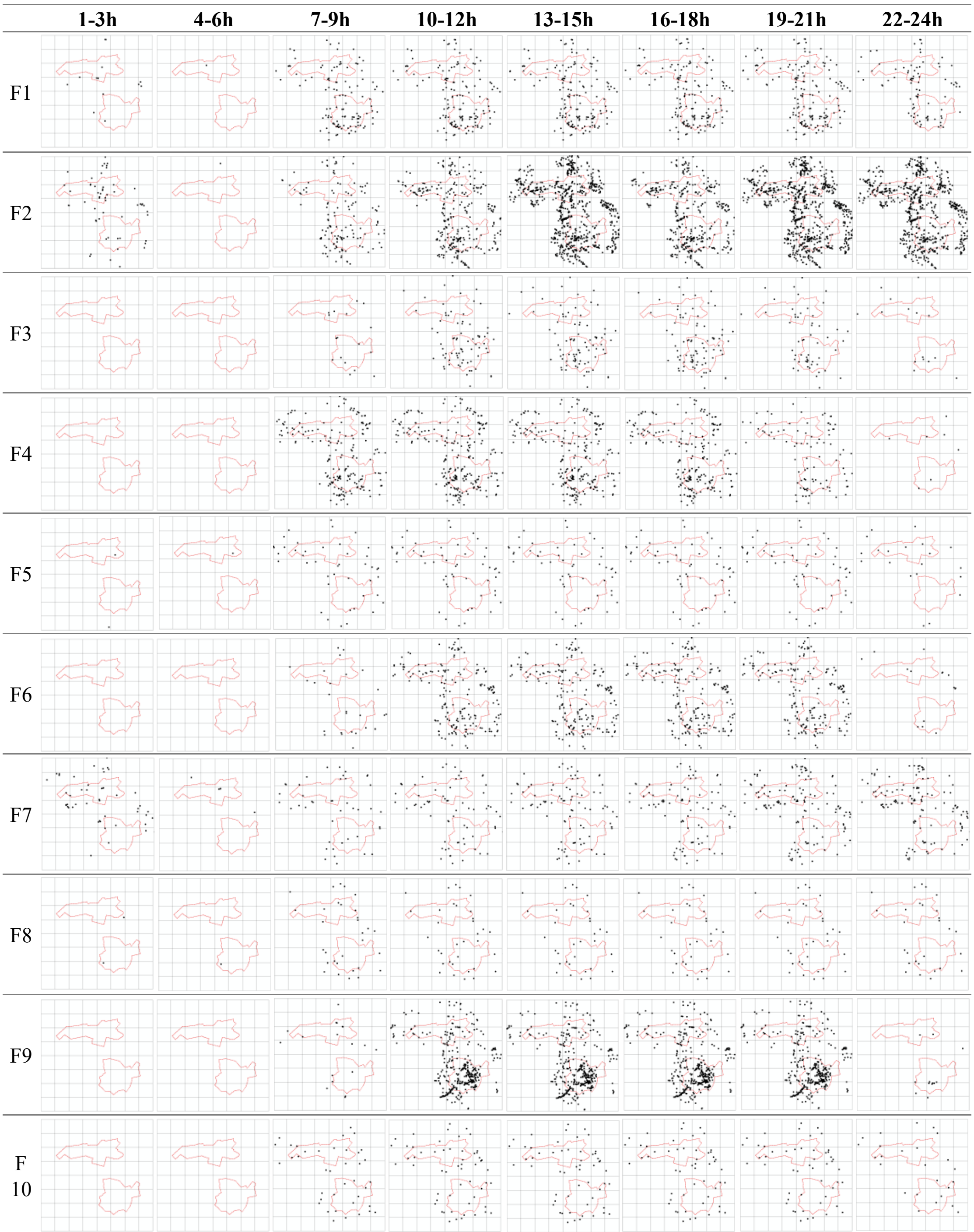
Fig 4.1-1 distribution of the activated functional points in space:
F1= café; F2= catering; F3= culture recreation; F4= daily service; F5= grocery; F6= local shop; F7= night life; F8= open space; F9= shopping place; F10= other recreation (grid: 500m)

In terms of quantity of 10 kinds of functional points, catering and shopping places are two kinds of most densely distributed categories compared with others. Catering has shown a relatively even distribution in the whole area, whereas shopping places are mainly concentrated in area of San Babila.

In most distribution of functional points, San Babila area has a higher density of distribution compared with China Town- Porta Nuova area, except distribution of groceries, night lives and outdoor recreations. It is interesting that there are no grocery shops in San Babila area. Another special phenomenon lies in distribution of cafés and night lives. Several concentrations of shops within small areas are found in these two categories, which is different from other categories which are relatively evenly distributed.

2. distribution of activated functional points of 10 categories in different time periods

Tab 4.1-1 distribution of activated functional points of 10 categories in different time periods: F1= café; F2= catering; F3= culture recreation; F4= daily service; F5= grocery; F6= local shop; F7= night life; F8= open space; F9= shopping place; F10= other recreation (grid: 500m)



This research is also trying to specify when the activated functional points are serving people during the day and night (Tab 4.1-1).

As is shown in the table, the vitality of cafés and caterings last longest among all the categories as activities can be found widely spread from 7.00 in the morning until 3.00 the next day. Generally for all the ten categories, time periods from 10.00 to 21.00 are the most visited. From 22.00 to 24.00, cafés, caterings, and night lives are the three main visited places. After 24.00 until 3.00 the next day, caterings and night lives are having more vitality. Time period from 4.00 to 6.00 can be considered as the least active as functional points are scarcely found visited for all categories even in night lives. From 7.00 on, functional points in seven categories (café, catering, daily service, grocery, night life, open space and other recreation) have observed a sudden boom in visitors, whereas similar kind of increase found in culture recreation, local shop and shopping place is postponed until 10.00.

Unexpected phenomenon discovered from the table include: firstly, for urban life after 22.00 until 3.00 the next day, 'night life' category is not the only choice as functional points belonging to catering are also visited; secondly, 'catering' is the only category which experiences 'double peaks' in time periods from 13.00 to 15.00 and time period after 19.00; thirdly, local shops and shopping places are special compares with other categories in that they both experiences sudden boom and drop in 10.00 and 21.00 which is not observed in any other functional points.

4.2 Function Pattern of Each Time Period

'Function of streets' in a limited sense is related with what is happening on each street. Streets in two area are clustered according two 10 categories of functions defined in Chapter 3. To make this process clear, functional pattern of each time period is described detailly firstly with result of clustering in space shown on the left as well as feature of clustering centers on the right (F1= café; F2= catering; F3= culture recreation; F4= daily service; F5= grocery; F6= local shop; F7= night life; F8= open space; F9= shopping place; F10= other recreation). Then functional streets in each time period are summarized in a table and alluvial diagrams of cluster transformation across times are given to make the functional changing pattern clear.

1. Function pattern of each time period during the week:

1-3h: as shown in Fig 4.2-1, most streets in this time period are found nearly having no visitors. By contrast, two patterns of streets are distinguished from others. First pattern is found in Galleria Vittorio Emanuele II, Piazza del Liberty, Moscova to Arco di Porta Garibaldi, Piazza Gae Aulenti and Via Ceresio for their high activity in catering. Second pattern is found in Porta Nuova, Via Luca Signorelli, Fondazione Giangiacomo Feltrinelli, Via Borgonuovo and streets near Terme Erculee for recreations.

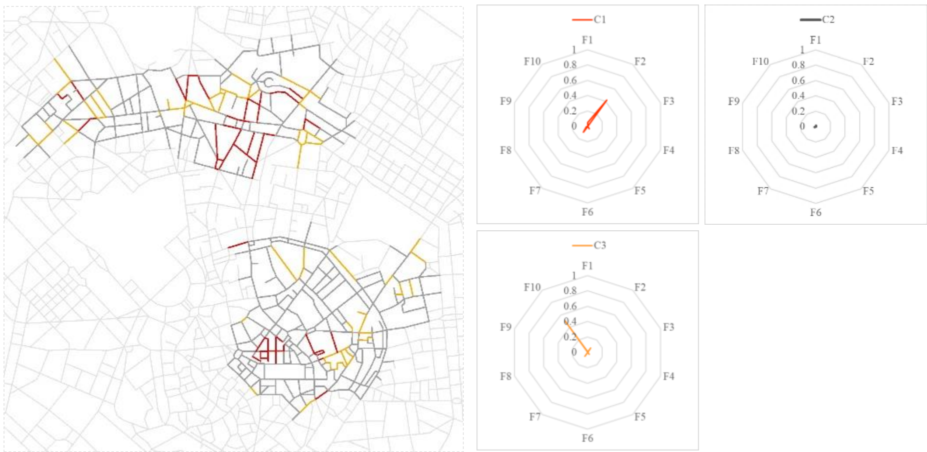


Fig 4.2-1 function pattern of 1-3h during the week

4-6h: streets in second pattern in 1-3h, which are high in recreations continue to be distinguished out in 4-6h for the same reason (Fig 4.2-2).

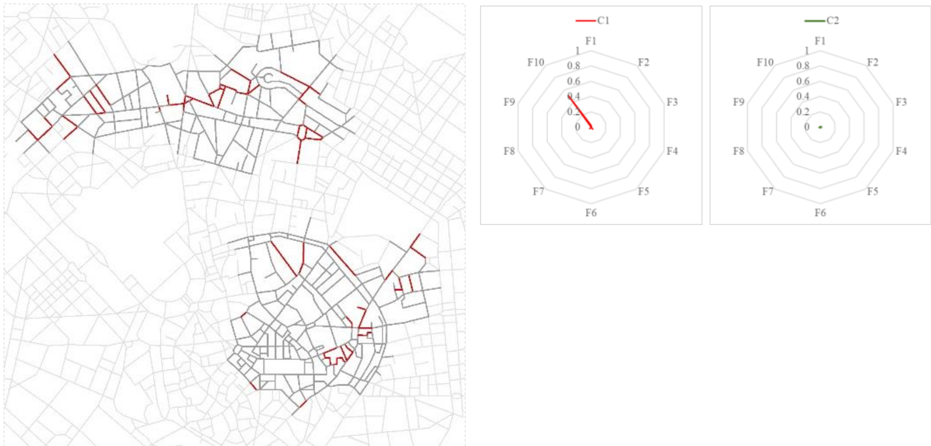


Fig 4.2-2 function pattern of 4-6h during the week

7-9h: beside streets succeeded from previous time periods, a new function pattern is found in Galleria Vittorio Emanuele II, Cordusio, Monument to Leonardo da Vinci, Palace of the Senate, Brera, Moscova to Arco di Porta Garibaldi and Porta Nuova (Fig 4.2-3). They are split out for their relatively higher ranking in culture recreations, caterings and night lives.

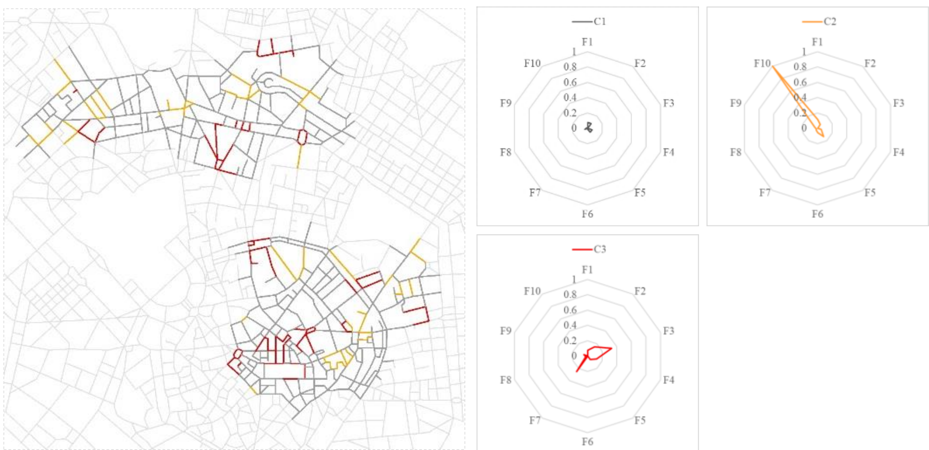


Fig 4.2-3 function pattern of 7-9h during the week

10-12h: during this time period, number of streets that are scarcely visited is apparently lessened (Fig 4.2-4) with two patterns of street function appear. Galleria Vittorio Emanuele II, Cordusio, Monument to Leonardo da Vinci, Palace of the Senate, Brera, Via Durini, Moscova, Arco di Porta Garibaldi, Piazza Gae Aulenti and Porta Nuova are grouped together because they are active in comprehensive functional types of cafés, caterings, daily services, local shops and shopping places. The other group of streets (mainly located in Brera, Palazzo Reale and Quadrilatero della Moda) are by contrast in extremely high rank in culture recreations.

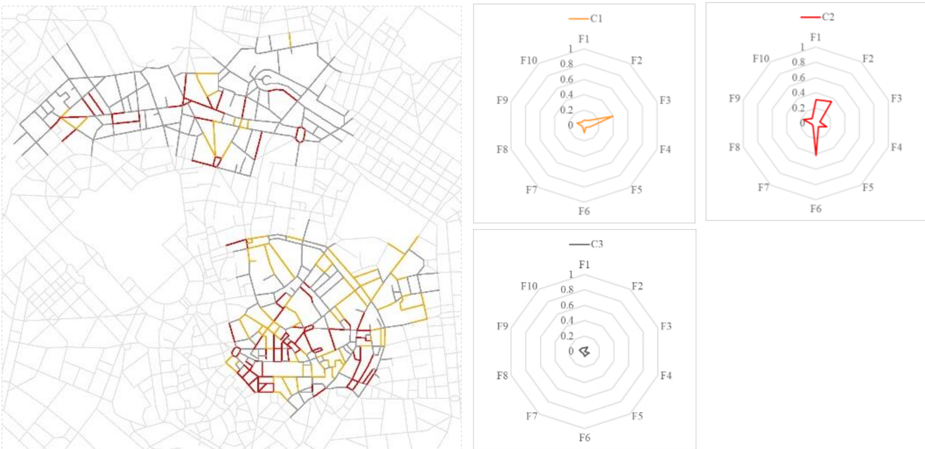


Fig 4.2-4 function pattern of 10-12h during the week

13-15h: time period from 13.00 to 15.00 is witnessing the most amplified types of function patterns (Fig 4.2-5), with two of them in comprehensive functions (C1 and C2). number of streets that are scarcely visited are further reduced.

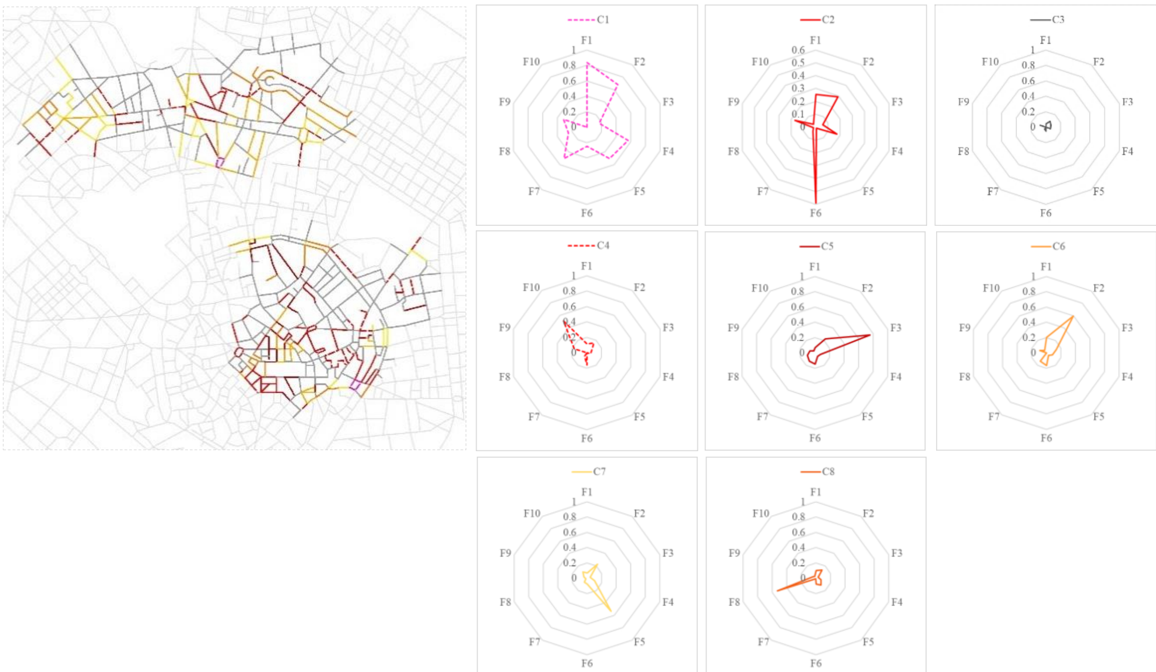


Fig 4.2-5 function pattern of 13-15h during the week

To be specific, besides streets in grey (C3) which are not activated compared with other streets, the other seven types of streets and their location are listed as follows: Moscova and Verziere Column are clustered as comprehensive functions of cafés, caterings, daily services, groceries, night lives and shopping places; comprehensive functions also distinguish Via Torino, Via Durini, Monument to Leonardo da Vinci, Piazza del Liberty, Fondazione Giangiacomo Feltrinelli as mixture of cafés, caterings, daily services, local shops and shopping place. The rest of patterns are all emphasizing single function, namely, other recreations (C4), culture recreations (C5), caterings (C6), groceries (C7) and open spaces (C8). Additionally, difference between area San Babila and area China Town- Porta Nuova begin to appear in this time period.

16-18h: streets in area San Babila and area China Town- Porta Nuova begin to fall in different patterns during this time period, and number of streets which are not active in any defined functions remain the same as 13-15h. More specifically, streets in San Babila are more clustered as composed use (C2: catering, culture recreation, local shop, night life and shopping place; C3: café, catering, daily service, local shop and shopping place); whereas streets in China Town- Porta Nuova are mainly detected less compound and rank lower by contrast (C1: local shop; C5: catering, grocery and open space). Moreover, function categories these two streets are emphasizing have shown great difference as streets in San Babila are more related with shopping, culture recreation and services; streets in China Town- Porta Nuova are more into grocery and local business in comparison.

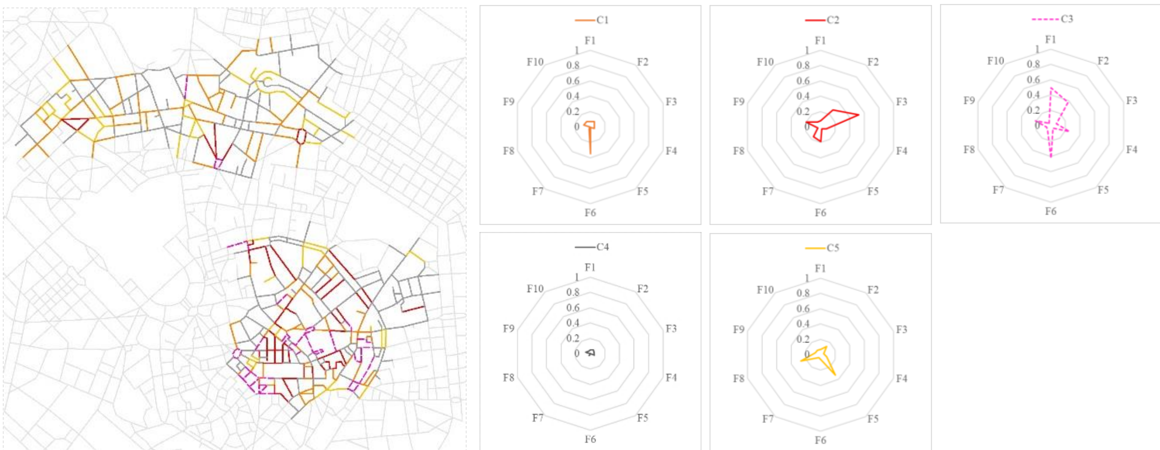


Fig 4.2-6 function pattern of 16-18h during the week

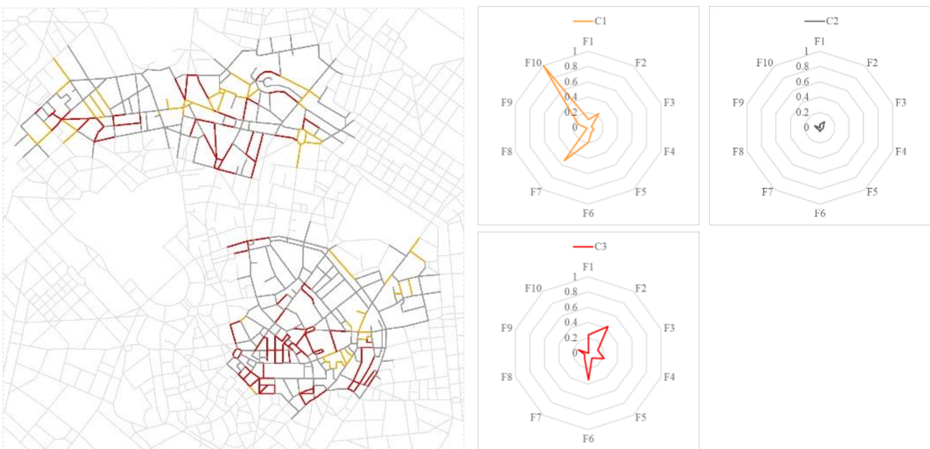


Fig 4.2-7 function pattern of 19-21h during the week

19-21h: during this time period, two street areas begin to integrate again as shown in Fig 4.6-7. Many streets which are detected as highly active previously become least vital, especially in Quadrilatero della Moda and Brera. Apart from streets in grey (C2) which are not active, streets in this time period can be divided into two kinds. The first is hugely focusing on other recreations and night lives (C1), which are found mainly in Porta Nuova, Arco di Porta Garibaldi, Via Luca Signorelli, and southwest of Piazza San Babila; and the rest which are in red in the map are in compound functions of caterings, daily services and local shops according to the clustering result.

22-24h: most street in this time period become inactive as shown in Fig 4.2-8 where these inactive streets are in grey (C1). During this time period, only three kind of functions are found to have higher vitality compared with others, namely, caterings, groceries and open spaces. Streets in C2 are found active in all these three functions, and they are mainly found in Via Luca Signorelli, Piazza Gae Aulenti, Porta Nuova, Cordusio and Monument to Leonardo da Vinci. Streets classified as C3 in red are most active in caterings, and they are located mainly in Moscova- Arco di Porta Garibaldi, Galleria Vittorio Emanuele II and Via Durini.

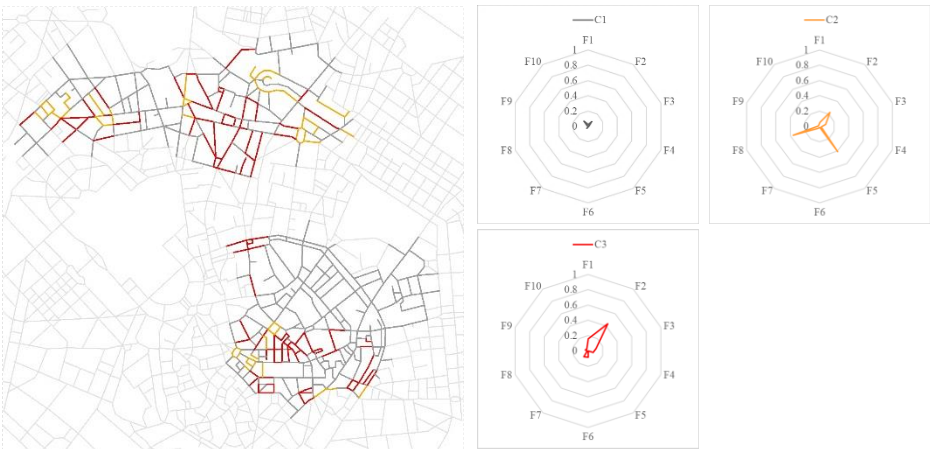


Fig 4.2-8 function pattern of 22-24h during the week

Summary

To sum up, during weekdays, the most amplified types of function patterns are found between 13.00 and 18.00, whereas in other time periods only two or three types of function patterns are discovered. During day times, streets are often clustered out by multi functions, composed or in single preference; and during the night hours, functions can be defined are mainly limited within several types: other recreations, caterings and groceries.

In terms of the two streets areas, they have many similarities in function patterns according to the clustering result, but the difference is still manifest especially during hours between 13.00 and 18.00.

2. Function pattern of each time period during the weekend:

1-3h: unlike what has been found for function patterns during the day, the first 3 hours during the weekend is showing relatively amplified types of function patterns (Fig 4.2-

9). Although most of the streets are still found inactive (C4), up to four types of active patterns of street function patterns are summarized as follows: first is function of open spaces (C1) found in Cordusio, Monument to Leonardo da Vinci, Verziere Column and Piazza Gae Aulenti; second is compound functions of cafés, caterings and night lives (C2) which are active in Moscova- Arco di Porta Garibaldi and Galleria Vittorio Emanuele II. Culture recreations are found in third pattern (C3) which are located in Galleria Vittorio Emanuele II and finally grocery pattern in Porta Nuova (C5).

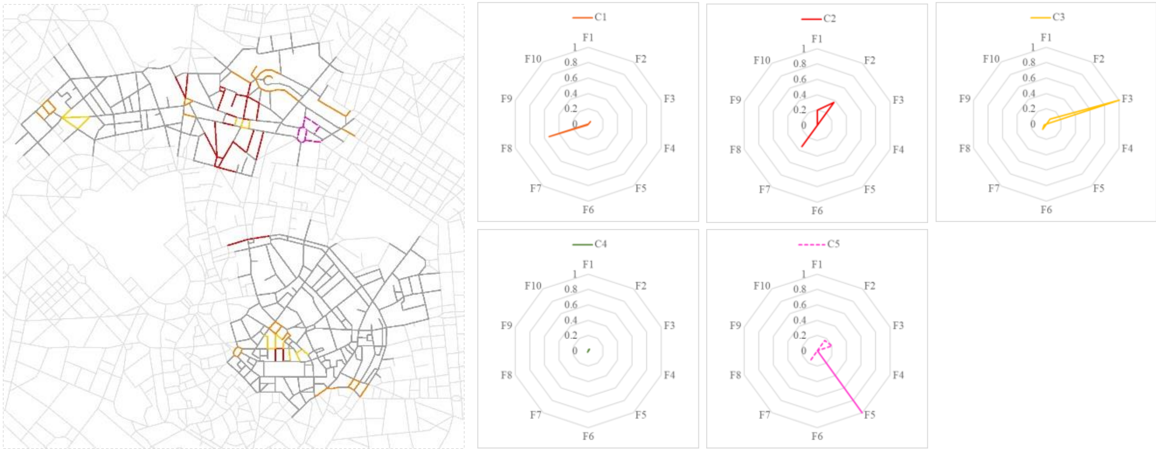


Fig 4.2-9 function pattern of 1-3h during the weekend

4-6h: this time period during weekend is having the most streets inactivated. Many streets in China Town- Porta Nuova are clustered out for their high vitality in functions of night lives and culture recreations according to Fig 4.2-10. Still, there are several streets found active in open spaces like Piazza Gae Aulenti, Monument to Leonardo da Vinci, Verziere Column.

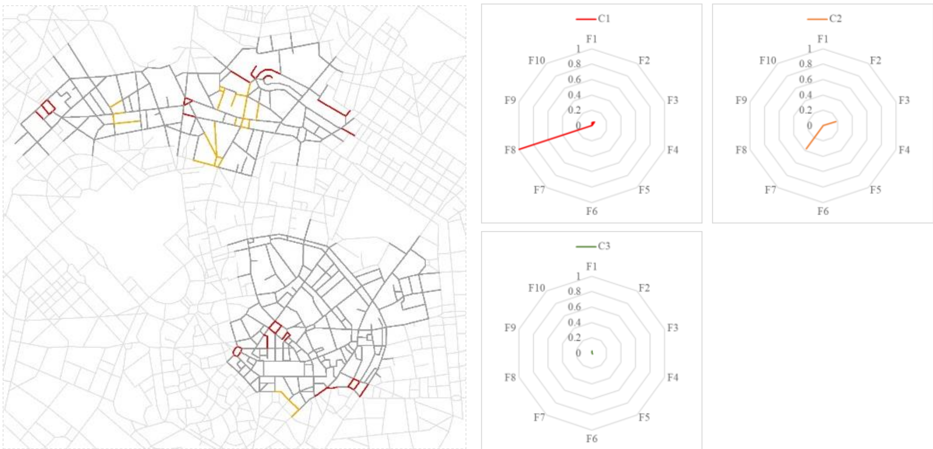


Fig 4.2-10 function pattern of 4-6h during the weekend

7-9h: many streets which are inactive previously start to gain visitors. Most amplified typed of function patterns are found during this time period during the weekend (4.2-11), but all emphasizing single function. To be specific, streets of ‘other recreation’ in Brera and Via Ceresio; streets of ‘café’ in southern part of Piazza San Babila and Piazza del Duomo; streets of ‘night life’ in Piazza Filippo Meda and Moscova; streets of ‘open space’ in Galleria Vittorio Emanuele II, Quadrilatero della Moda, Brera, Piazza Gae Aulenti and Arco di Porta Garibaldi; streets of ‘catering’ in Via Paolo Sarpi and Piazza

Gae Aulenti; and streets of ‘groceries’ in Porta Nuova and Via Paolo Sarpi.

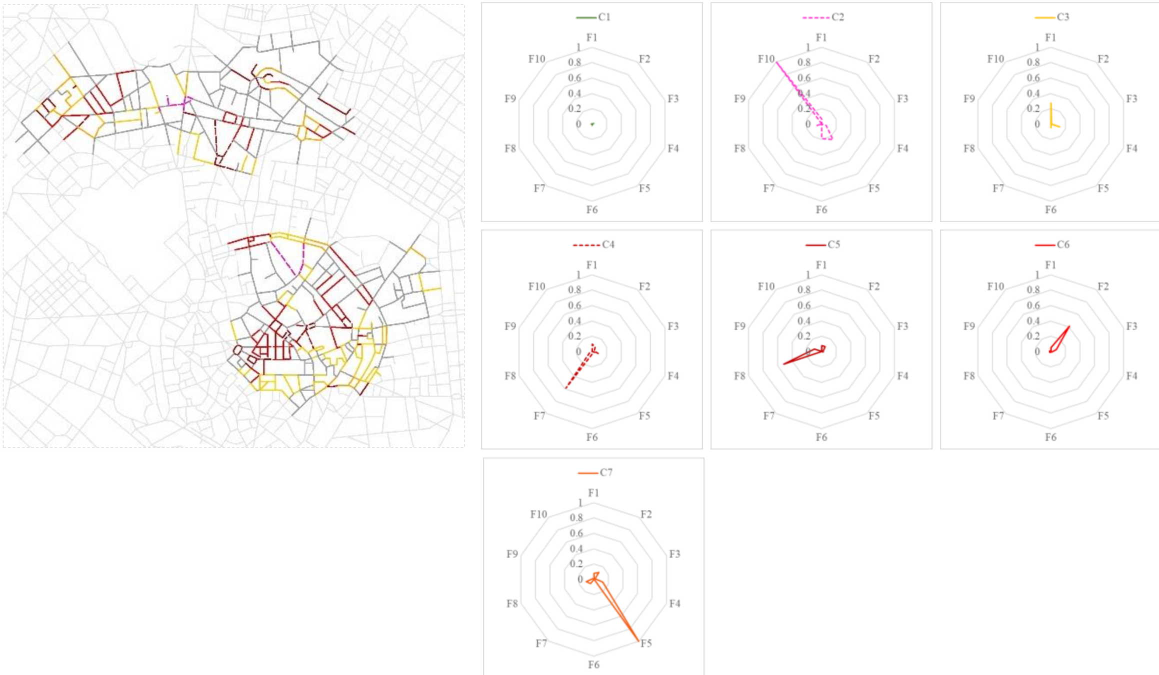


Fig 4.2-11 function pattern of 7-9h during the weekend

10-12h: streets in C5 category which is found inactive have experienced a further decrease compared with data in time period from 7.00 to 9.00. Difference between area San Babila and area China Town- Porta Nuova become apparent during this time period (Fig 4.2-12), although there are also integration of the two street areas. For streets in San Babila, main function patterns include C3 which is mainly distinguished by culture recreations and C2 which is clustered out by compound functions of café, catering, local shop and shopping place. By contrast, streets in China Town- Porta Nuova have fallen mainly in C1 and C4 patterns which are highly ranked in terms of groceries and other recreations respectively.

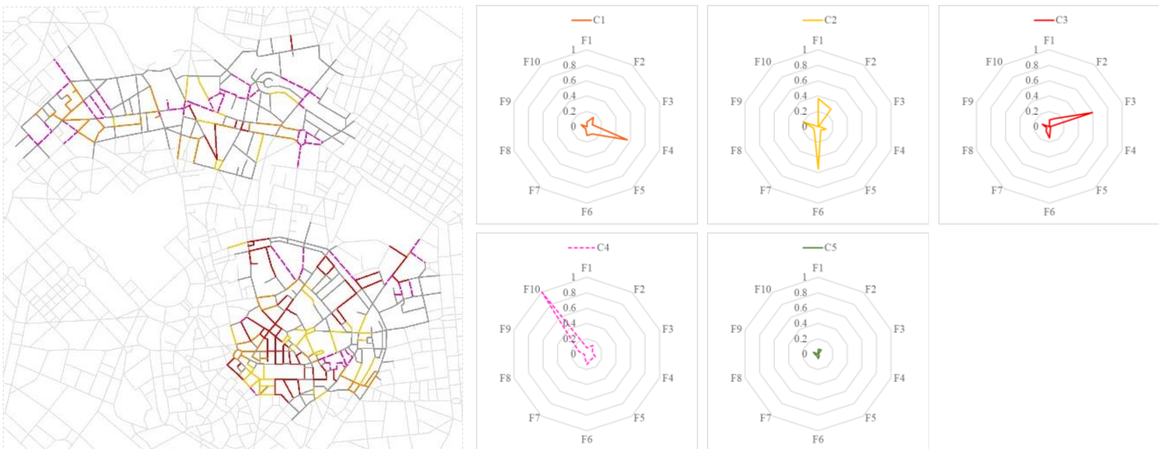


Fig 4.2-12 function pattern of 10-12h during the weekend

13-15h: number of streets that are activated reaches the peak in this time period compared with data of the whole day. However, the patterns of function of streets have converged into less types (Fig 4.2-13). Three patterns of street function are listed except

C2, where streets are not active. First pattern is distinguished by culture recreations, which is found in Piazza del Duomo and Quadrilatero della Moda (C1). Second pattern composed of café, catering, local shop and shopping place is mainly located in Piazza del Liberty – Piazza San Babila, and Moscova- Arco di Porta Garibaldi (C3). Whereas streets Via Paolo Sarpi, Porta Nuova, Verziere Column and Cordusio are clustered together for their high rank in function of groceries.

Fig 4.2-13 function pattern of 13-15h during the weekend

16-18h: in this time period, streets become less active compared with previous hours of 13.00 to 15.00 and fewer number of function patterns are detected (only three) (Fig 4.2-14). Compound functions are feature of this time period and they are quite different when comparing the two study areas. Specifically, function pattern of C1 is distinguished by function of café, catering, culture recreation, local shop and shopping place. They can be mainly found in area San Babila and Moscova- Arco di Porta Garibaldi in area China Town- Porta Nuova. The other type of streets are defined by functions of catering, grocery and local shops, and they are located mainly in Porta Nuova and Via Paolo Sarpi.

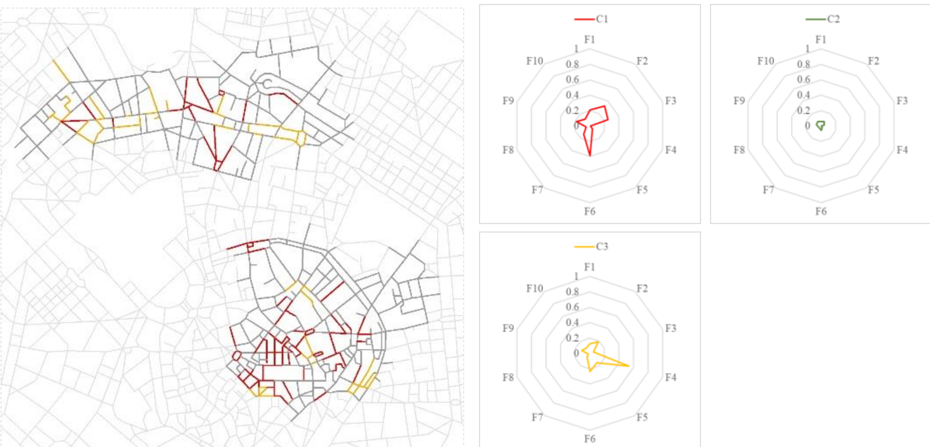


Fig 4.2-14 function pattern of 16-18h during the weekend

19-21h: compound functions continue from 16-18h until this time period, however the two research areas begin to integrate at the same time. Function pattern composed of catering, daily service and grocery are found in Porta Nuova and Via Paolo Sarpi for China Town- Porta Nuova; and in Verziere Column and Brera for San Babila area.

Moreover, function pattern which is distinguished by catering, local shop and open space is observed in area from Piazza del Duomo to Piazza San Babila in San Babila and area of Moscova- Arco di Porta Garibaldi in area China Town- Porta Nuova (Fig 4.2-15).

Fig 4.2-15 function pattern of 19-21h during the weekend

22-24h: compared with the same time period during week days, 22-24h during the weekend is quite different for its variety of function patterns, especially for streets in area China Town- Porta Nuova which is generally more active than area San Babila (Fig 4.2-16). Function pattern of C2 which ranks high in functions of café and catering is the most widely distributed. Streets of this pattern include Galleria Vittorio Emanuele II, Verziere Column, Brera, Moscova- Arco di Porta Garibaldi and Via Paolo Sarpi. Funciton pattern composed of catering and culture service (C1) is only found in area San Babila whereas catering in China Town- Porta Nuova is accompanied by groceries and daily services (C3).

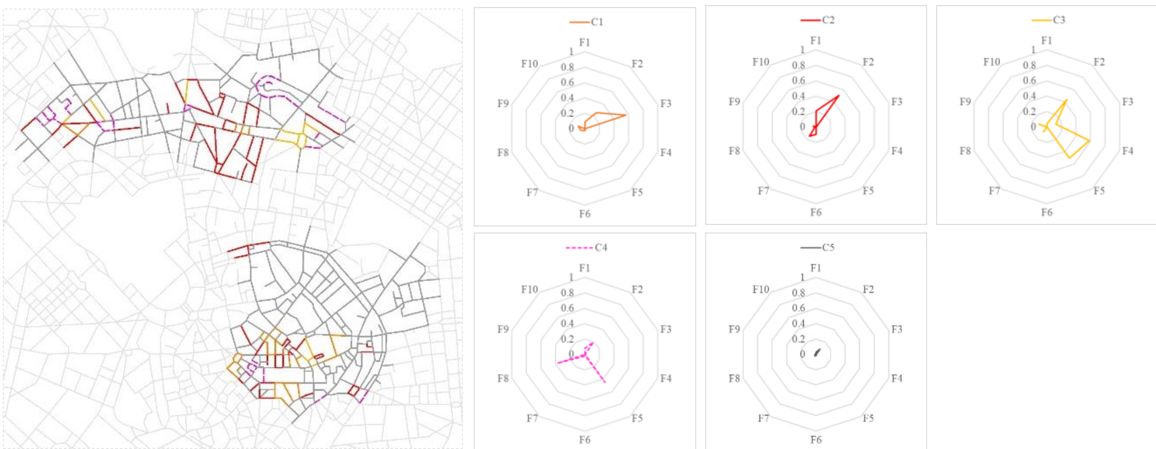


Fig 4.2-16 function pattern of 22-24h during the weekend

Summary

To sum up, during week days, the most amplified types of function patterns are found between 7.00 and 18.00, and between 22.00 and 3.00 the next day; whereas in other time periods only two or three types of function patterns are discovered. Additionally, the difference between the two street areas enlarges during peak hours by the different types of services provided, namely, grocery and local businesses for China Town- Porta Nuova and shopping for area San Babila. And the difference between the two districts is lessened in other time periods.

4.3 Functional Changing Patterns of Streets

Functional changing patterns cannot be summarized into specific kinds due to the focus on ‘functions’ from limited sense. Diversity kinds of defined functions make the clustering happened only for each time period as ‘functional patterns’ and the clustering of streets complex. Still, this research is trying to sum up the functional changing patterns from limited sense.

To make the changing patterns clear, two summarized tables of functional patterns during the week and weekend are given with validation of SSE (sum of square errors) and Silhouette coefficient (Tab 4.3-1, Tab 4.3-2).

1. Functional changing pattern of streets during the week

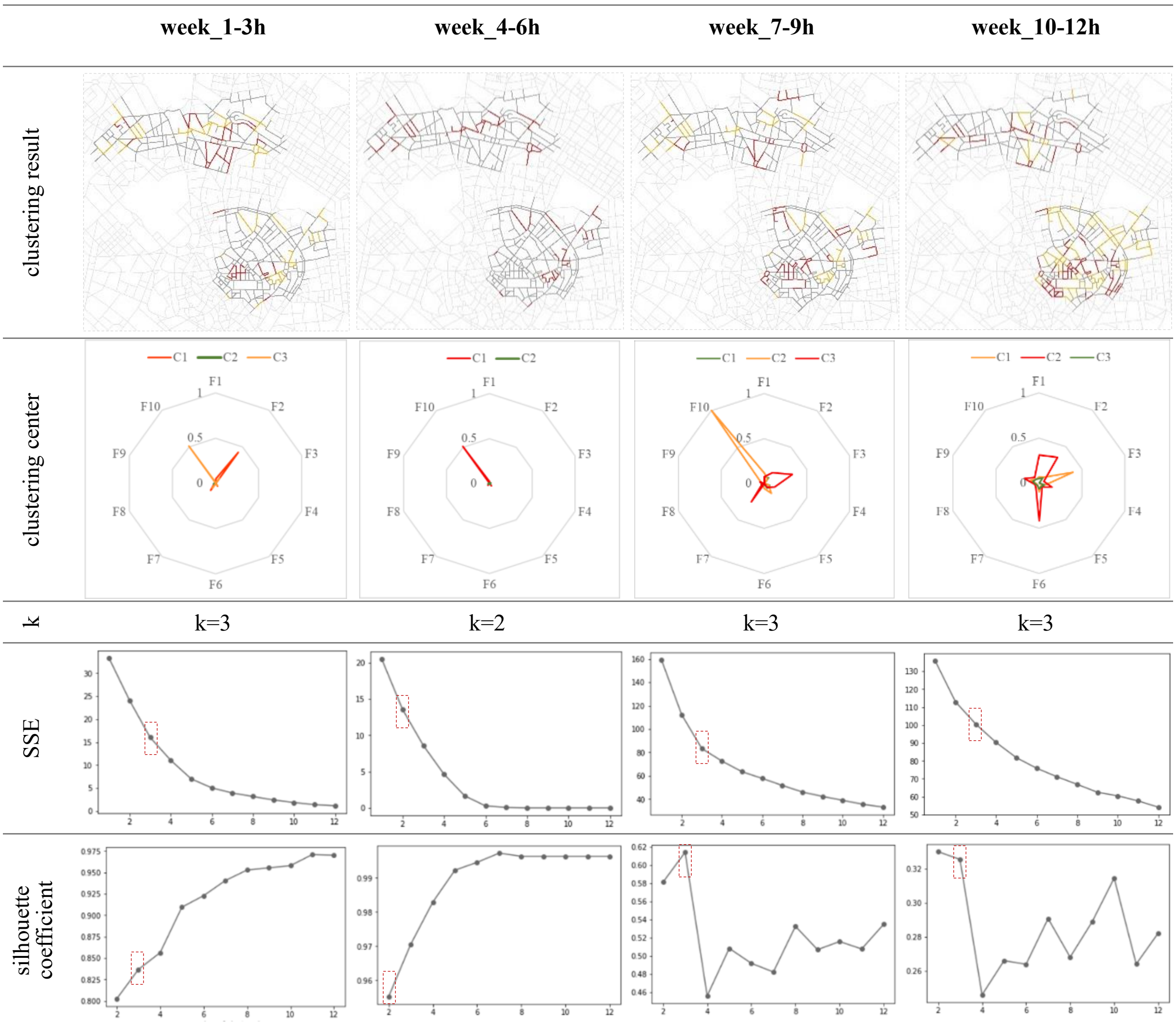
Tab 4.3-1 has illustrated the result in clustering function patterns for each time period during the week.

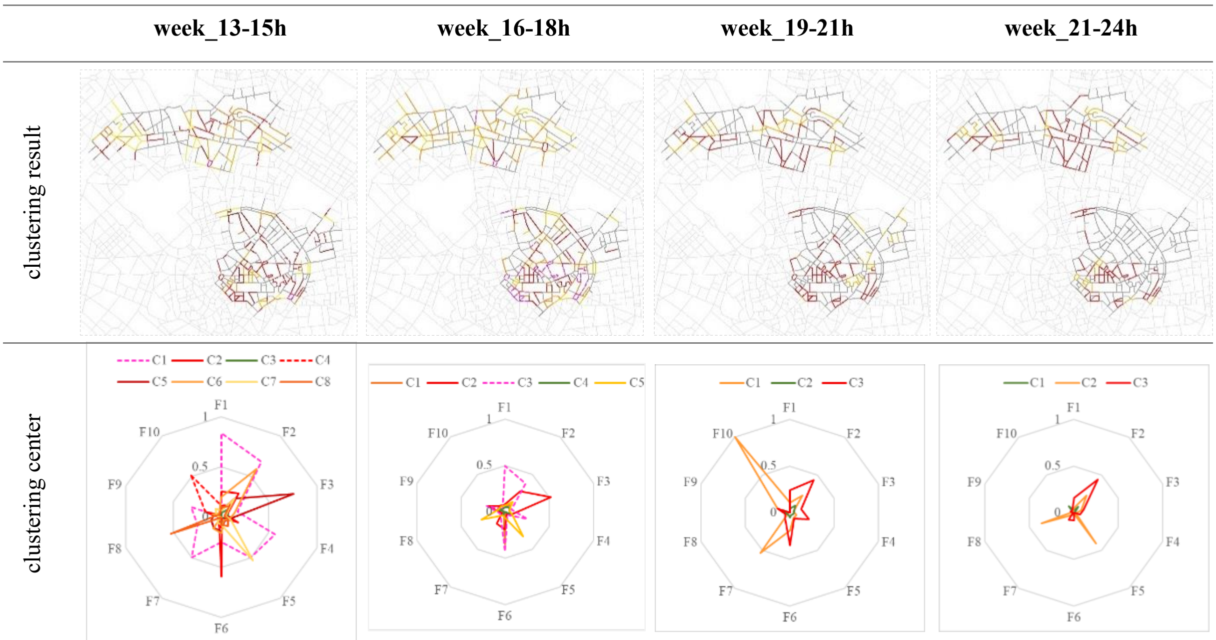
Temporally, the functional changing pattern can be summarized by if the streets are ‘active’. The whole area owns the least vitality between 4.00 and 6.00 compared with other times of the day. After 7.00, streets start to become active and gradually reach the peak in vitality after 10.00. The situation of the vitality sustains until 18.00, before the value begin to decrease.

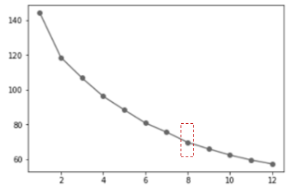
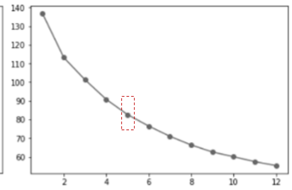
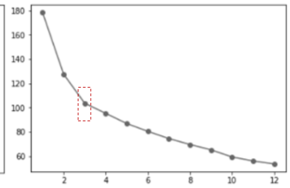
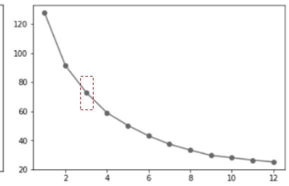
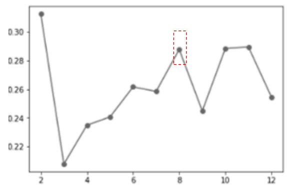
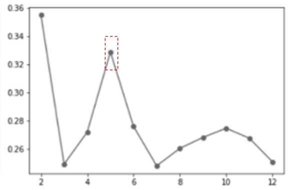
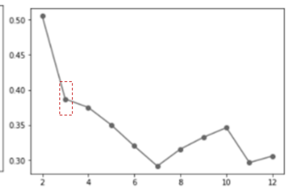
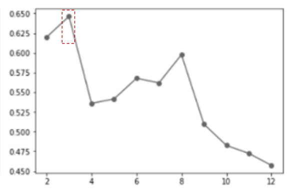
In terms of 10 kinds of defined functions, the streets are classified based on more categories of functions when they are more active. Additionally, when the streets are more active, more patterns of function can be found and there are more compound functions.

Combined with spatial features, difference between two street areas is apparent. Firstly, streets in San Babila are generally more active than streets in China Town- Porta Nuova during the day and this pattern is conversed during the night. Secondly, the two areas are distinguished by different functional features, as streets in China Town- Porta Nuova are emphasizing more groceries and local shops whereas streets in San Babila are having more shopping places, culture recreations and daily services. Similarities between the two street areas lie in that during the night, the two areas are sharing same function patterns.

Table 4.3-1: Characteristics of functional streets in each time period during the week: **panel 1:** clustering result in space; **panel 2:** k value: the final clustering numbers defined; **panel 3:** clustering centers: F1= café; F2= catering; F3= culture recreation; F4= daily service; F5= grocery; F6= local shop; F7= night life; F8= open space; F9= shopping place; F10= other recreation; **panel 4:** SSE for the number of clusters from 1 to 12; **panel 5:** Silhouette index for the number of clusters from 2 to 12.



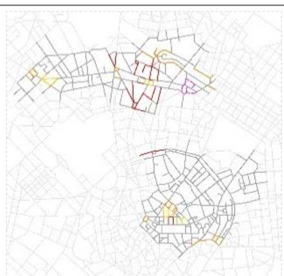
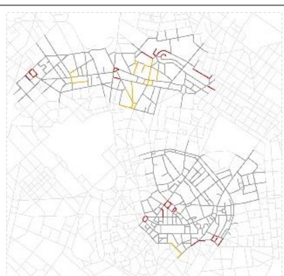
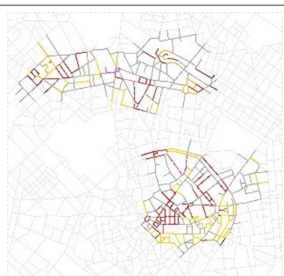
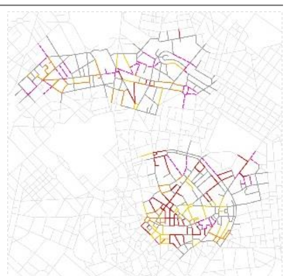
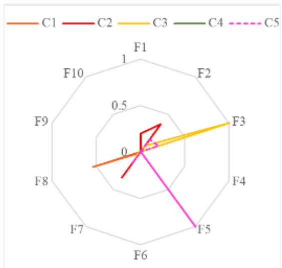
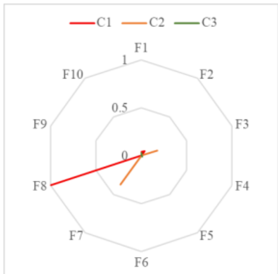
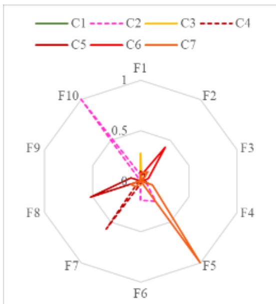
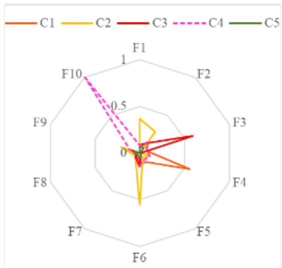
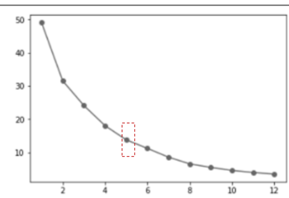
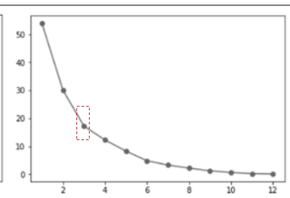
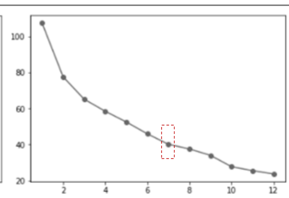
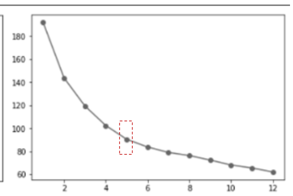


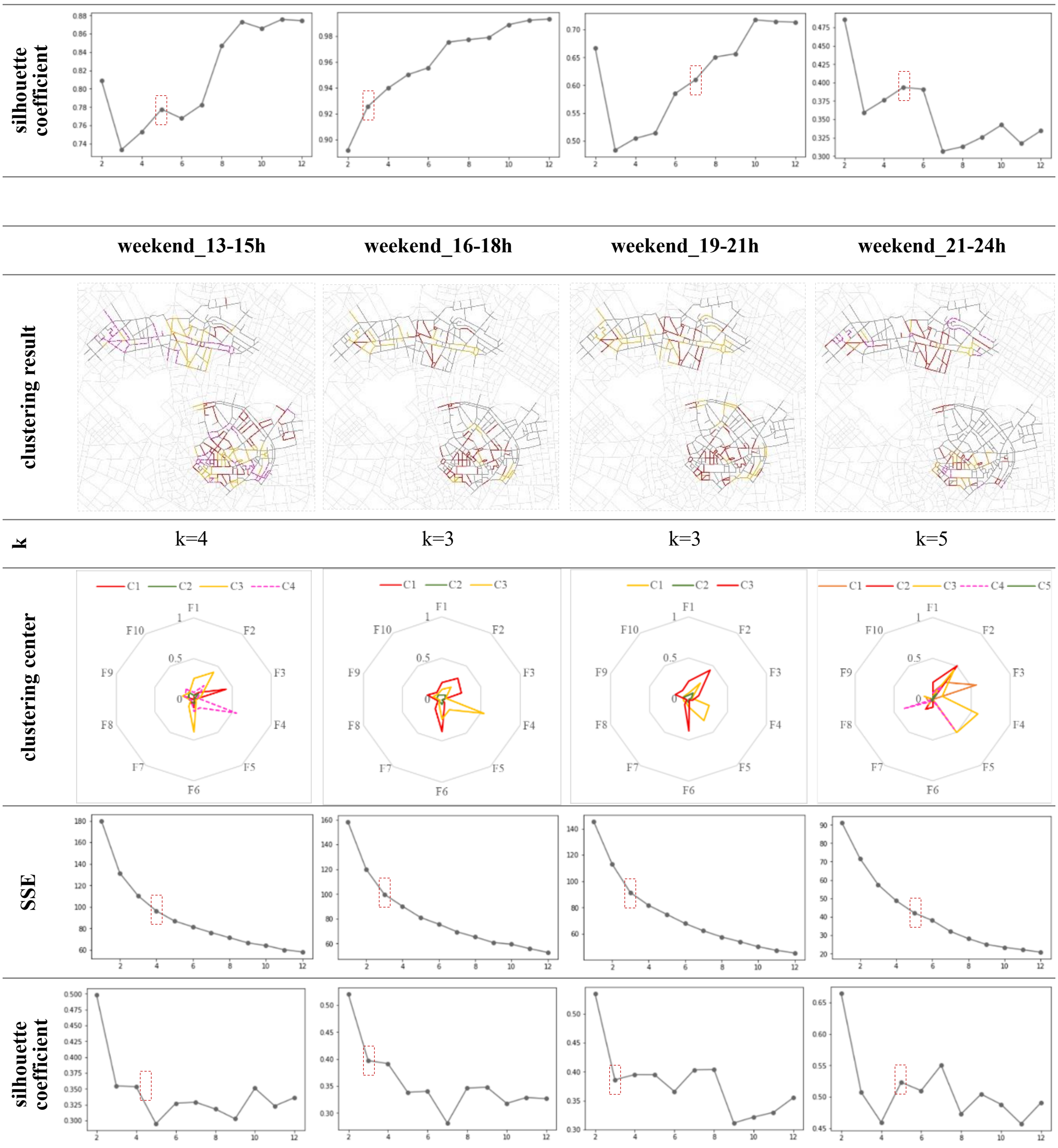
k	k=8	k=5	k=3	k=3
SSE				
silhouette coefficient				

2. Functional changing pattern of streets during the weekend

Tab 4.3-2 is showing the result in clustering function patterns for each time period during the weekend.

Table 4.3-2: Characteristics of functional streets in each time period during the weekend: **panel 1:** clustering result in space; **panel 2:** k value: the final clustering numbers defined; **panel 3:** clustering centers: F1= café; F2= catering; F3= culture recreation; F4=daily service; F5= grocery; F6= local shop; F7= night life; F8= open space; F9= shopping place; F10= other recreation; **panel 4:** SSE for the number of clusters from 1 to 12; **panel 5:** Silhouette index for the number of clusters from 2 to 12.

	weekend_1-3h	**weekend_4-6h**	**weekend_7-9h**	**weekend_10-12h**
clustering result				
clustering center				
k	k=5	k=3	k=7	k=5
SSE				



Temporally, the functional changing pattern can be summarized by if the streets are 'active'. The whole area owns the least vitality between 4.00 and 6.00 compared with other times of the day. After 7.00, streets start to become active and gradually reach the peak in vitality after 10.00. The situation of the vitality sustains with only a small decrease until 24.00, which indicates high activity intensity during the night hours.

Like what is happening during the week, the streets are classified based on more categories of functions when they are more active during the weekend. Additionally, when the streets are more active, more patterns of function can be found and there are more compound functions.

Besides difference between the two areas proposed in functional changing patterns during the week, in this part, spatial feature of streets during the evenings are discussed.

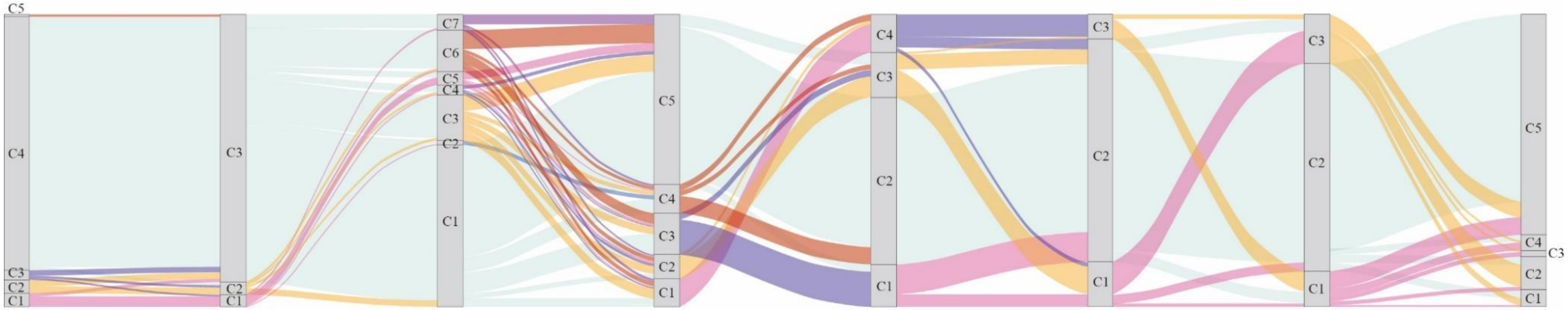


Fig 4.4-1 Alluvial diagram of cluster transformation across 8 time periods during the weekend

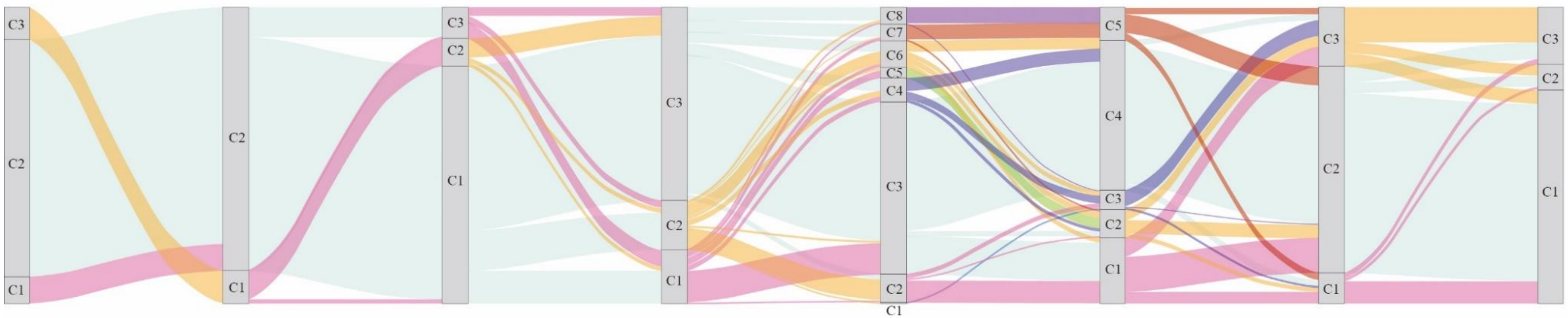


Fig 4.4-2 Alluvial diagram of cluster transformation across 8 time periods during the week

To be specific, after 17.00, the two street areas are experiencing high vitality except Quadrilatero della Moda. The activated situation of China Town- Porta Nuova sustains until 3.00 the next morning when area of San Babila becomes less active.

4.4 Summary

Generally, the functional patterns can be summarized as follows:

All streets except those are always inactive are following pattern of least vitality between 4.00 and 6.00 and start to become active until they gradually reach the peak in vitality after 10.00. Afterwards, difference between days during the week and weekend start to appear. To better understand functional changing patterns, Fig 4.4-1 and Fig 4.4-2 have presented alluvial diagrams of cluster transformation across 8 time periods during the weekend and the week. Light green in the image are clusters where the streets are inactive. As is manifest in the images, after 10.00 streets are more active during the weekend than during the week and the leading trend maintains until 24.00. Moreover, types of function patterns are more amplified during the weekend than that during the week.

Difference between two street areas lie in their different functional features, as streets in China Town- Porta Nuova are emphasizing more groceries and local shops whereas streets in San Babila are having more shopping places, culture recreations and daily services. Furthermore, during more active hours, the function patterns defined by clustering are more related with compound functions.

Combining the temporal and spatial features, the functional changing patterns can be summarized into the following types:

Pattern 1: two street areas are of '7-24' vitality, namely, Galleria Vittorio Emanuele II and Moscova- Arco di Porta Garibaldi;

Pattern 2: activated only during peak hours, and different from connected areas, which is found in streets in area Quadrilatero della Moda;

Pattern 3: having relatively high vibrancy during the day but not active during the night, and distinguished by compound functions of daily services, local shops, shopping places and culture recreations during peak hours. This type is mainly found in Cordusio, streets around Piazza del Duomo all the way until southern Piazza San Babila and Arco di Porta Garibaldi - Piazza Gae Aulenti;

Pattern 4: distinctive for open spaces and culture recreations during peak hours and activated by additional functions of caterings and local shops during other time of the day. This type of pattern is found in Brera;

Pattern 5: having relatively high vibrancy during the day but with only several streets staying active during the night, and distinguished by compound functions including groceries, caterings and local shops during peak hours. Streets with this pattern are mainly located in core area of China Town, connected with Via Paolo Sarpi.

Pattern 6: generally staying relatively inactive during the whole day. Streets in this pattern include streets outside the old city wall, Via Gaetano de Castillia and Via Ceresio which divide China Town and Porta Nuova area.

Chapter 5 Functional Changing Pattern in General Terms (Functional Connectivity)

5.1 Measurement of Functional Connectivity

‘Function of street’ in general terms in this dissertation is defined by people’s usage as function of the specific street and function connectivity of the street within given radius. For every street in given time period and given walking distance, define indicators as follows:

1. Function connectivity of streets

‘Street function’ in this part is to detect the feature of every single street from density and diversity. It is considered that within a single street, the delivery of functional nodes is instant without any waste of time.

Density.

Density measures the accumulation of scored activities of the specific segment node. This essay has defined three kinds of density, first is proportion of activated functional nodes bearing google popular time data which shows the efficiency of space usage; second is number of people on unit length of road which shows the absolute utility of the street; third is number of activated functional points on unit length of road which represents utility of space along the streets.

Diversity.

Diversity measures the balance degree of all reachable scored activities of the specific segment node. Quantities of researches have proved that concentration of diverse and mixed activities can improve urban vitality and sustainability, consuming less of transportation and acquiring higher level of social cohesion at the same time. In this article, diversity is measured from two perspectives: activated functional nodes and check-ins of people. There are many methods available for measuring diversity, among them entropy index is the most widely accepted and commonly used index for representing the land-use mix. Entropy generally quantifies homogeneity of land use in a given area, which is negatively correlated with diversity. Hence, diversity in this essay is expressed as:

$$\mathrm{DIV} = -\sum_{k=1}^{k} P_k \cdot \frac{\ln (P_k)}{\ln (K)} \qquad (1)$$

Where:

For activated functional nodes, P_k = proportion of total number of activated functional nodes of k^{th} function category found in the street being analyzed; K = total types of activated functional nodes considered in the street;

For check-ins of people, P_k = proportion of total number of check-ins on k^{th} function category found in the single street being analyzed; k = total number of check-ins on the street;

Delivery.

For single segment node, delivery means how reachable is the street in the city. In this research, indicators of 'choice' and 'integration' are chosen directly from Space Syntax theory to measure the streets. 'Choice' means how likely an axial line or a street segment it is to be passed through on all shortest routes from all spaces to all other spaces in the entire system or within a predetermined distance (radius) from each segment; 'integration' measures how many turns have to be made from a street segment to reach all other street segments in the network, using shortest paths, and can also be limited to a defined area or the entire system. Both these two indicators are calculated within a defined radius of 750m in this article.

Unlike delivery measured in function connectivity, delivery here measures the basic function of streets without the concept of 'usage by people', and is the only element existing even when nobody is using the space. In later on clustering process, streets that own only delivery in street function perspective will not take part in process of grouping in that they can be clearly made into a group without people's usage.

2. Function connectivity in defined walking radius

Different from street function, 'function connectivity' is to detect how the specific street is connected with surrounding streets within given distance. In this part, the research has defined 2 radiuses of 300 m and 500 m on basis of people's walking habits which are 3-5min and 10 min walk respectively. The range of the area is defined by people's walking trajectory using Network Analysis in ArcGIS. Two of the dimensions of function connectivity as density and diversity are the same as street function except the study area (single street vs area), whereas new dimension of 'delivery' is introduced to measure usage efficiency.

Density.

Density measures the accumulation of scored activities from each street within a defined radius. In function connectivity, density is measured as sum up of all segment nodes' function within the radius.

Diversity.

Diversity measures the balance degree of all reachable scored activities from the original street within given distance. Using same equation (1) as diversity measurement in street function, For activated functional nodes, P_k = proportion of total number of activated functional nodes of k^{th} function category found in the area being analyzed; k = total number of activated functional nodes considered in the area; For check-ins of people, P_k = proportion of total number of check-ins on k^{th} function category found in the whole area being analyzed; k = total number of check-ins in the area;

Delivery.

Delivery is introduced as an independent dimension in different definition compared with delivery in single street because function connectivity in this article is considered in walking trajectory in reality. This index is total metric length of streets with activated functional nodes divided by the walking area, revealing the cognitive efficiency of function delivery from all reachable function nodes to the original street in terms of energy expenditure measured in density of trajectory.

3. Indicator system for measuring functional connectivity

Through this step, an indicator system can be established into 3-D modle and it is summarized in table below (Table 5.1-1) so that for each time period of each street the function feature can be calculated.

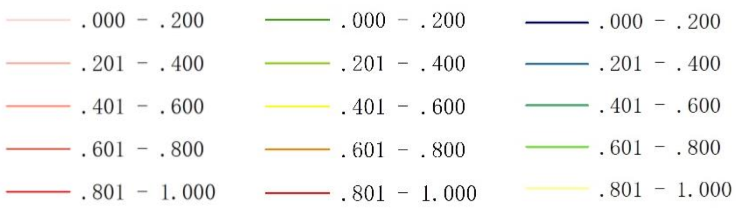
Table 5.1-1: indicators for measuring functional connectivity of street

Dimension	Perspective	Indicators	Calculation	Unit
Functional connectivity of street	Density	efficiency of space usage	percentage of activated functional nodes on segment node	%
		density of activated functional nodes	number of activated functional nodes on unit length of street	/m
		density of people's usage	number of check-ins on unit length of street	/m
	Diversity	diversity of activated functional nodes	entropy formula (1)	--
		diversity of people's usage		--
Functional Connectivity within given radius (300m and 500m walking distance)	Density	efficiency of space usage	percentage of activated functional nodes within defined radius	%
		density of activated functional nodes	average of density of activated functional nodes of all segment nodes within defined radius	/m
		density of people's usage	average of density of people's usage of all segment nodes within defined radius	/m
	Diversity	diversity of activated functional nodes	entropy formula (1)	--
		diversity of people's usage		--
	Delivery	cognitive efficiency of function delivery from segment node to all reachable activated function nodes	total metric length of streets with activated functional nodes divided by the walking area	/m

For the calculation of functional connectivity, data of indicators are normalized and added according to each perspective; and data of each perspective is normalized and added into functional connectivity.

5.2 Feature of Pre-processed Data

According to previous definition, functional connectivity within streets is defined by density and diversity; and functional connectivity for streets in walking distance of 300m and 500m is defined by density, diversity and delivery. In this research, feature of density, diversity and delivery is shown. All the data has been normalized between 0 and 1 for further summation of functional connectivity. To make the graphs easier to understand, this research has specified legends for each perspective. (Fig 5.2-1)



(a) (b) (c)

Fig 5.2-1 specified legends for each perspective: (a) density; (b) diversity; (c) delivery

1. Functional connectivity within streets

Density: Table 5.2-1 and Table 5.2-2 are showing the change of density of each street during the week and the weekend respectively. Overall, the changing mode of density during the week and the weekend are quite similar with people starting to accumulate between 10.00 and 12.00, the density peaking between 16.00 and 21.00, and the accumulation turning to several isolated 'islands' in Galleria Vittorio Emanuele II; Moscova - Arco di Porta Garibaldi - Porta Nuova; and streets near Corso Sempione after 21.00. It is very interesting that before 9.00, it seems that the density value is always below 0.2 which might be different from situation in reality.

Table 5.2-1 density during the week (within streets)

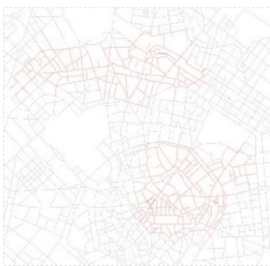
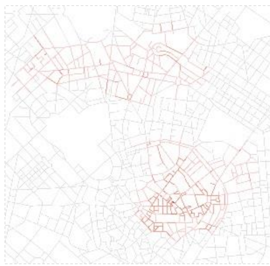
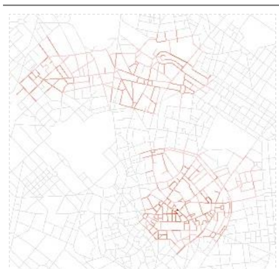
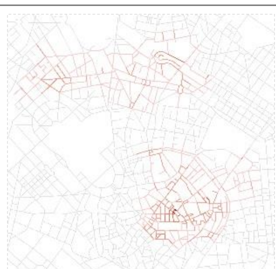
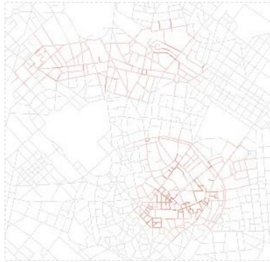
week_1-3h	**week_4-6h**	**week_7-9h**	**week_10-12h**
			
week_13-15h	**week_16-18h**	**week_19-21h**	**week_21-24h**
			

Table 5.2-2 density during the weekend (within streets)

weekend_1-3h	weekend_4-6h	weekend_7-9h	weekend_10-12h
			
weekend_13-15h	**weekend_16-18h**	**weekend_19-21h**	**weekend_21-24h**
			

Spatially, the difference between streets is manifest. Area of San Babila has higher density than area China Town- Porta Nuova as a whole. To be specific, area from Piazza del Duomo till Piazza San Babila has always been the densest area of all time. From 10.00 this area has already witnessed accumulation of people, which is earlier than other places, and stays most active all day long. Linked with Piazza San Babila, Quadrilatero della Moda and area Brera are quite different in that the density decreases sharply after 19.00. For area China Town- Porta Nuova, concentration is observed in Moscova - Arco di Porta Garibaldi - Porta Nuova; and streets near Corso Sempione rather than evenly distributed throughout the area. Concentration of people and activities peaks at periods of 13.00 – 15.00 and 16.00- 18.00. An interesting phenomenon is that the range of concentration after 21.00 in China Town- Porta Nuova is larger than that in Galleria Vittorio Emanuele II.

Diversity: Table 5.2-3 and 5.2-4 are showing the change of diversity of each street during the week and the weekend respectively. Generally speaking, it is manifest that the distribution of diversity on streets is following a multi-center pattern. There are many centers made up by several streets that have far more activity diversity than surrounding streets. Data for diversity during week and weekend is sharing similar changing mode. Time period of 4.00 to 6.00 owns the least diversity when the value of all streets are below 0.4 and most of them below 0.2. Afterwards, the diversity value is increasing gradually with the passing of time and peaks between 13.00 to 18.00. Places that owns the highest diversity decrease after 19.00 and drop dramatically after 21.00.

The main difference between data for density the changing mode of density during the week and the weekend lies in streets during the week 'wake up' earlier than that during the weekend. This is exhibited by data from 7.00 to 9.00, where number of streets during the week whose diversity value are above 0.4 is far more than that during the weekend.

Table 5.2-3 diversity during the week (within streets)

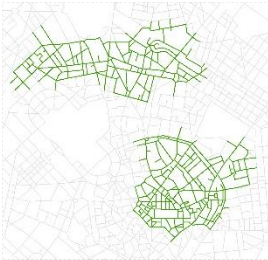
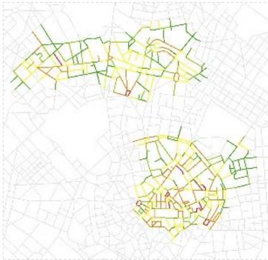
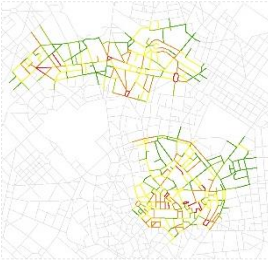
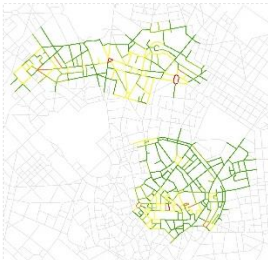
week_1-3h	week_4-6h	week_7-9h	week_10-12h
			
week_13-15h	**week_16-18h**	**week_19-21h**	**week_21-24h**
			

Table 5.2-4 diversity during the weekend (within streets)

weekend_1-3h	weekend_4-6h	weekend_7-9h	weekend_10-12h
			
weekend_13-15h	**weekend_16-18h**	**weekend_19-21h**	**weekend_21-24h**
			

Spatially, the difference between the two streets areas lies in that the number of streets who are playing the role of diversity centers in San Babila is more than that in China Town- Porta Nuova. And the distribution of diversity centers in San Babila is far denser than that in China Town- Porta Nuova, which is manifest in data for time periods of 10.00 to 21.00. Diversity centers in San Babila are closely connected with each other especially in area expanding from Piazza del Duomo till Piazza San Babila. By contrast, diversity centers in China Town- Porta Nuova are relatively independent from each other, namely, Via Paolo Sarpi and Via Luigui Canonica; streets connected to Moscova; and streets near Porta Nuova. Among all the streets, places near Porta Nuova are most special in that they are especially diverse during the night compared with other streets (value above 0.8) and with themselves during the day. Like data for density, Quadrilatero della Moda and area Brera are quite different in that the diversity decreases sharply after 19.00.

2. Functional connectivity within 300m walk

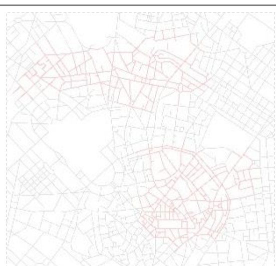
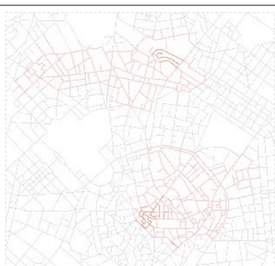
When expanding the connectivity measurement to a walking distance of 300m, it is clear that for density, diversity and delivery, phenomenon of functional ‘connectivity regions’ can be discovered. Compared with data for single streets, which is showing several street ‘centers’ in space, ‘connectivity regions’ are different in that they are not made up by several connected streets but a continuous region of streets. This may be explained by the fact that for some streets who are inferior in connectivity, 300 m walking distance is enough to send people from segment nodes of these streets to other more connected streets.

Density: Table 5.2-5 and Table 5.2-6 are showing the change of density of each street during the week and the weekend respectively. The density changing mode of selected streets during the week and the weekend are similar to each other, both start increasing form 7.00 and peaks during periods from 13.00 to 15.00, after which decrease gradually until 21.00 when the data see a sharp drop.

In comparison of the two districts, area of San Babila has higher density than China Town- Porta Nuova except in time period of 21.00 to 24.00, when the range of connectivity region in China Town- Porta Nuova which has higher density is larger than that in San Babila.

The distribution of functional connectivity regions is following ring structure. The core of ring has the most people accumulated. For most of time periods, the core of density are Galleria Vittorio Emanuele II and Piazza del Duomo in San Babila district and Moscova - Arco di Porta Garibaldi - Porta Nuova; streets near Corso Sempione in China Town- Porta Nuova district. Although connected, China Town and Porta Nuova are two districts on map. For San Babila district, the second ring and third ring are made up of streets within inner and outer ring of the city; where as for China Town- Porta Nuova district, only two layers can be observed, core and the rest streets. The core region of China Town- Porta Nuova can only compete with the second ring of San Babila district, which shows the extremely high attraction of traditional city center.

Table 5.2-5 density during the week (within 300m walk)

week_1-3h	**week_4-6h**	**week_7-9h**	**week_10-12h**
			

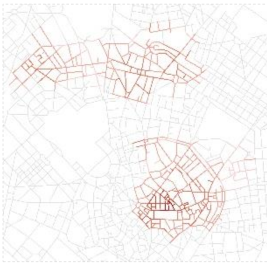
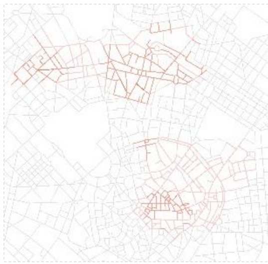
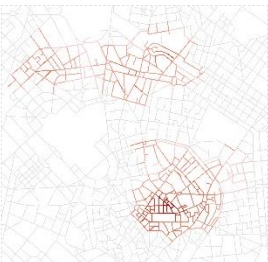
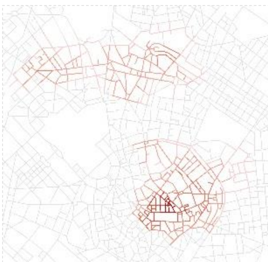
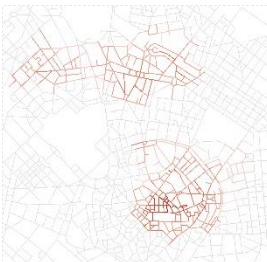
week_13-15h	week_16-18h	week_19-21h	week_21-24h
			

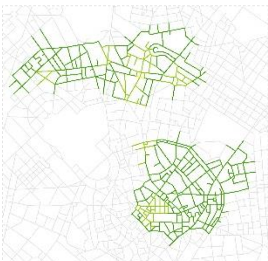
Table 5.2-6 density during the weekend (within 300m walk)

weekend_1-3h	weekend_4-6h	weekend_7-9h	weekend_10-12h
			
weekend_13-15h	**weekend_16-18h**	**weekend_19-21h**	**weekend_21-24h**
			

Diversity: Table 5.2-7 and 5.2-8 are showing the change of diversity of each street during the week and the weekend respectively. Generally, the changing mode of diversity is following similar mode for data during the week and the weekend. Time period of 4.00 to 6.00 is the least diverse after which the value gradually increases and peaks at time periods of 13.00 to 18.00. After 19.00, the value of diversity decreases and drops suddenly after 21.00 before it returns to time period of 4.00 to 6.00.

The main difference between the two areas lies in that the diversity value of San Babila district is significantly higher than that of China Town- Porta Nuova.

Table 5.2-7 diversity during the week (within 300m walk)

week_1-3h	week_4-6h	week_7-9h	week_10-12h
			

week_13-15h	week_16-18h	week_19-21h	week_21-24h
			

Table 5.2-8 diversity during the weekend (within 300m walk)

weekend_1-3h	weekend_4-6h	weekend_7-9h	weekend_10-12h
			
weekend_13-15h	**weekend_16-18h**	**weekend_19-21h**	**weekend_21-24h**
			

Like distribution of density, distribution of diversity is also following the ring structure. Core of the ring has the most diverse kind of activities happening. For most of time periods, the core of diversity are Piazza del Duomo to Piazza San Babila and Quadrilatero della Moda in San Babila district and Moscova - Arco di Porta Garibaldi - Porta Nuova; streets near Corso Sempione in China Town- Porta Nuova district. It is very interesting that a move of diversity core can be observed in San Babila area, where for time period 7.00 to 9.00, the diversity core is Galleria Vittorio Emanuele II to Cordusio rather than Piazza del Duomo to Piazza San Babila and Quadrilatero della Moda, the most diverse area in most time of the day. After 21.00, the cores move back again to Piazza del Duomo, Galleria Vittorio Emanuele II and their surroundings.

Delivery: in the last dimension of delivery, the changing mode is quite different from data of density and diversity. The delivery value of streets remain stable in most time of the day (from 10.00 to 21.00) and the distribution is not following the ring structure. Some high delivery cores can be observed from the map in this time period, namely, Via Paolo Sarpi and Via Luigui Canonica, streets connected to Moscova, and streets near Porta Nuova in China Town- Porta Nuova; Galleria Vittorio Emanuele II to Cordusio, Quadrilatero della Moda, Piazza San Babila and Corso Europa.

During other time periods, like data for density and diversity, period of 4.00 to 6.00 owns the least efficiency of travel. And for time periods of 21.00 to 24.00 and 1.00 to 3.00, an unexpected phenomenon is that delivery of streets in China Town- Porta Nuova has higher efficiency than that in San Babila district. This can be inferred for the reason that road density in some areas are higher than others.

Table 5.2-9 delivery during the week (within 300m walk)

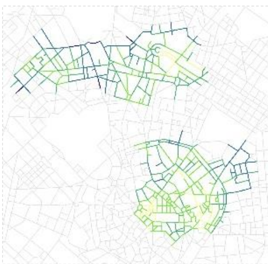
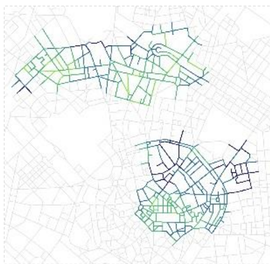
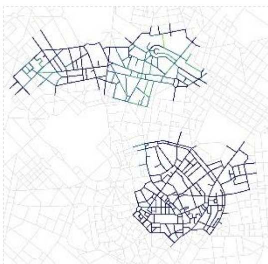
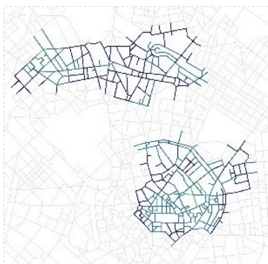
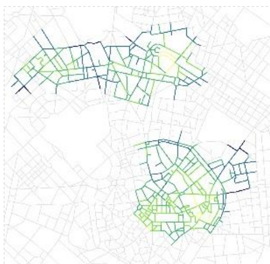
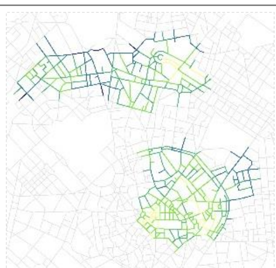
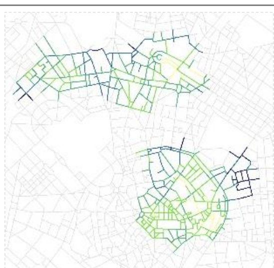
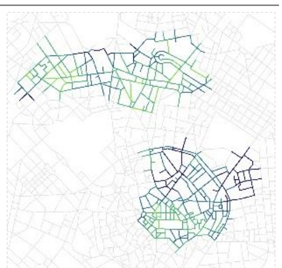
week_1-3h	week_4-6h	week_7-9h	week_10-12h
			
week_13-15h	**week_16-18h**	**week_19-21h**	**week_21-24h**
			

Table 5.2-10 delivery during the weekend (within 300m walk)

weekend_1-3h	weekend_4-6h	weekend_7-9h	weekend_10-12h
			
weekend_13-15h	**weekend_16-18h**	**weekend_19-21h**	**weekend_21-24h**
			

3. Functional connectivity within 500m walk

When continue to expand the connectivity measurement to a walking distance of 500m, the number of functional connectivity regions decrease, and the area of each region increase. Distribution of density, diversity and delivery all follow the ring structure.

Density: Table 5.2-11 and Table 5.2-12 are showing the change of density of each street during the week and the weekend. The changing mode of density during the week and the weekend are similar, both start increase between 7.00 and 9.00, peaking between 13.00 and 18.00 before the value decrease. The only difference lies in time period from 7.00 to 9.00, when for days during the week the accumulation of people already start especially in Galleria Vittorio Emanuele II, Cordusio and Piazza del Duomo whereas for days during the weekend the accumulation of people is not manifest.

500m walking distance make area of China Town- Porta Nuova homogeneously distributed in density for most time of the day (10.00 to 21.00). For San Babila area in this time period, only two rings of connectivity regions can be observed. The core is made up of Galleria Vittorio Emanuele II to Cordusio, Piazza del Duomo to Piazza San Babila and the surrounding streets. Area of Quadrilatero della Moda is special for streets in this area is moving between regions. In time period from 13.00 to 18.00, the value of density in Quadrilatero della Moda belong to the core connectivity region whereas in other time periods, this area belongs to outer region which has less density.

Table 5.2-11 density during the week (within 500m walk)

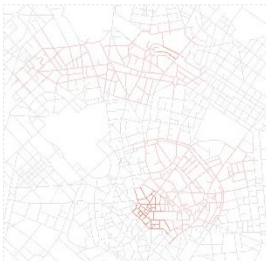
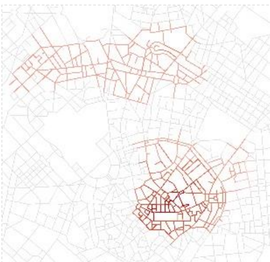
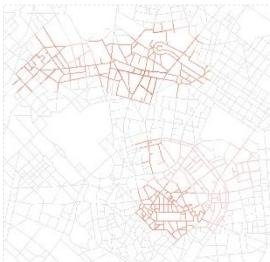
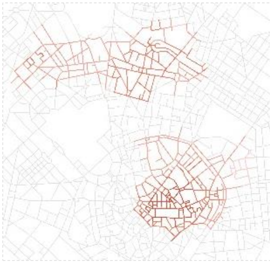
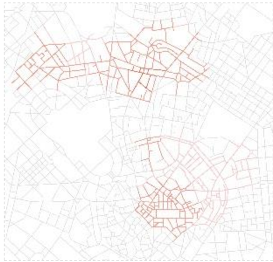
week_1-3h	**week_4-6h**	**week_7-9h**	**week_10-12h**
			
week_13-15h	**week_16-18h**	**week_19-21h**	**week_21-24h**
			

Table 5.2-12 density during the weekend (within 500m walk)

weekend_1-3h	**weekend_4-6h**	**weekend_7-9h**	**weekend_10-12h**
			

weekend_13-15h	weekend_16-18h	weekend_19-21h	weekend_21-24h
			

Diversity: Table 5.2-13 and Table 5.2-14 are showing the change of diversity of each street during the week and the weekend respectively. The overall changing mode of diversity is similar to the mode of 300m walking distance. The most diverse kinds of activities are observed mainly in time period of 10.00 to 21.00, when value of diversity are above 0.8 in Piazza del Duomo to Piazza San Babila, Quadrilatero della Moda and their surrounding streets; and in Moscova - Arco di Porta Garibaldi - Porta Nuova; streets near Corso Sempione. After 21.00, the core of diversity move to Galleria Vittorio Emanuele II to Cordusio in San Babila, and area around Arco di Porta Garibaldi, and the diversity remain highest until 6.00 the next day.

Table 5.2-13 diversity during the week (within 500m walk)

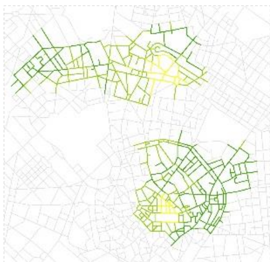
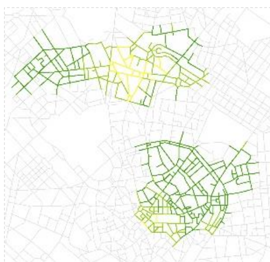
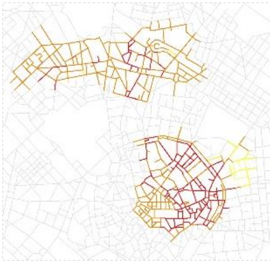
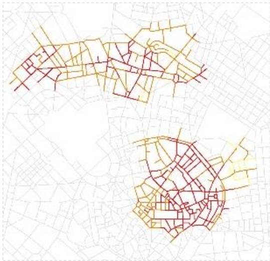
week_1-3h	week_4-6h	week_7-9h	week_10-12h
			
week_13-15h	**week_16-18h**	**week_19-21h**	**week_21-24h**
			

Table 5.2-14 diversity during the weekend (within 500m walk)

weekend_1-3h	weekend_4-6h	weekend_7-9h	weekend_10-12h
			

weekend_13-15h	weekend_16-18h	weekend_19-21h	weekend_21-24h
			

Delivery: Table 5.2-13 and Table 5.2-14 are showing the change of diversity of each street during the week and the weekend respectively. Unlike delivery in 300m walking distance, the distribution of delivery is following the ring structure.

Value of delivery stays relatively stable between 10.00 and 21.00, during which Piazza del Duomo all the way to Piazza San Babila owns the highest efficiency of travelling, with streets in Quadrilatero della Moda and Brera of the secondary efficiency. For time periods from 7.00 to 9.00 and from 21.00 to 24.00, number of connectivity regions decrease and only value of delivery in core region is relatively higher than that of outer connectivity regions.

Discussion of special time periods and spatial features is also exhibited here. Firstly, Moscova - Arco di Porta Garibaldi - Porta Nuova and Piazza Gae Aulenti during the weekend are especially active, whereas during the week, time period from 1.00 to 6.00 is witnessing nearly no travelling. Secondly, there are some streets which are always not well connected with activities, namely, Via Ceresio which is dividing China Town and Porta Nuova; streets that made up the Sforzesco Castle Walls of the city and streets outside Sforzesco Castle Walls. This might be caused by the fact that the allocation of activities of the city is usually avoiding the main traffic infrastructures.

Table 5.2-15 delivery during the week (within 500m walk)

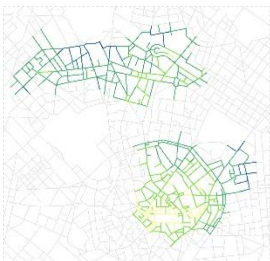
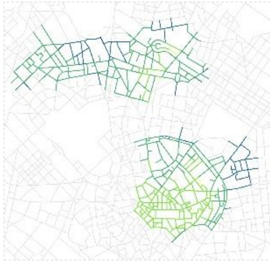
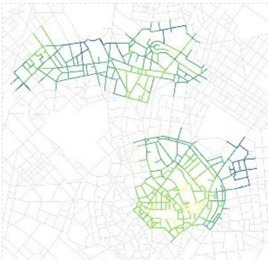
week_1-3h	week_4-6h	week_7-9h	week_10-12h
			
week_13-15h	**week_16-18h**	**week_19-21h**	**week_21-24h**
			

Table 5.2-16 delivery during the weekend (within 500m walk)

weekend_1-3h	weekend_4-6h	weekend_7-9h	weekend_10-12h
			
weekend_13-15h	**weekend_16-18h**	**weekend_19-21h**	**weekend_21-24h**
			

To conclude, changing mode of functional connectivity for days during the week and the weekend are quite similar, in terms of density, diversity and delivery. The only difference lies in that streets of weekdays 'wake up' earlier than that during the weekend; and activity during weekend last longer till the next day than week days. Time period from 13.00 to 18.00 has always been the most active whereas time period from 4.00 to 6.00 has always been the least active. Spatially, area of San Babila is more active than China Town- Porta Nuova, except during night hours, streets of Moscova- Porta Nuova can exceed.

With the expanding of the radius in considering the connectivity (within single street; 300m walking distance; 500m walking distance), the distribution of connectivity is changing from multi centers to ring structure, validating the fact that street network is a linked system.

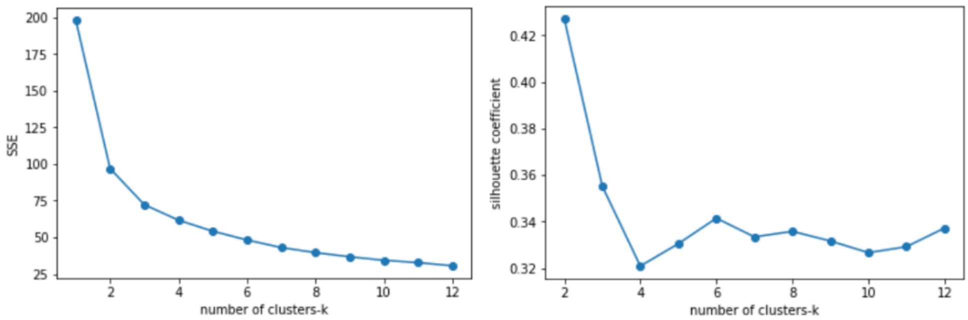
5.3 Functional Connectivity Areas and Functional Changing Patterns

Because of the similarity between data of the week and data of the weekend, the clustering process is combining both data during the week and data during the weekend. The specific methods used for clustering has been shown in chapter 3. Additionally, due to the dramatic difference in distribution patterns with the expanding of the unit for calculation of functional connectivity, this research is clustering streets by different walking distances respectively.

For each dimension, two aspects of result are provided in this dissertation. Spatially, the result of clustering is show in space, with different groups using different colors. In this sense, a continuous area with the same color is called a 'functional connectivity area'. Statistically, the changing mode of comprehensive connectivity is visualized by line graph to make the comparison between groups clear.

1. Functional connectivity within streets

Fig 5.3-1 shows the process of defining number of groups in clustering streets by change of functional connectivity within streets. According to SSE map, number of clusters should be 3 (elbow at 3). This is validated by silhouette index map that the index peaks when number of clusters is 3.



(a) (b)

Fig 5.3-1 defining number of groups in clustering streets by change of functional connectivity within streets: (a) SSE for the number of clusters from 1 to 12; (b) Silhouette index for the number of clusters from 2 to 12.

Fig 5.3-2 shows the result of clustering by change of functional connectivity within streets spatially. Although in different areas, many streets in China Town- Porta Nuova share same functional connectivity changing pattern with streets in traditional city center (San Babila). In addition, it is manifest from the map that the functional connectivity areas are quite small, usually made up by several streets. The only large continuous functional connectivity area is observed in San Babila, made up by Galleria Vittorio Emanuele II- Cordusio; Piazza Filippo Meda; Piazza del Liberty and part of Corso Vittorio Emanuele II.

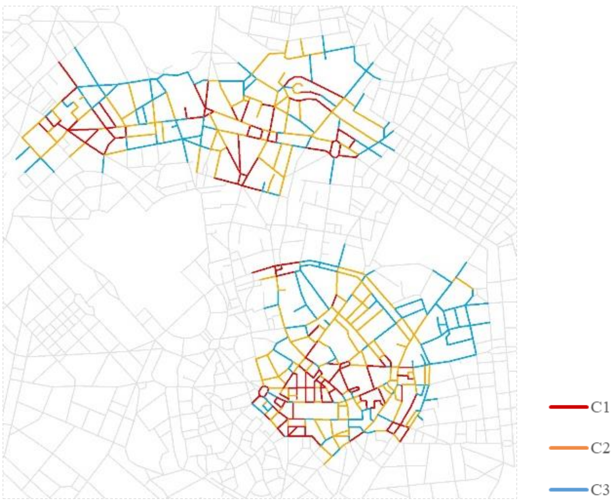


Fig 5.3-2 result of clustering in space

The functional connectivity changing pattern of the three clustering centers are illustrated in Fig 5.3-3. According to the map, lines for 3 clustering centers have no intersections, which means functional connectivity for Cluster1 stays highest of all time, Cluster2 remains in the middle, and Cluster3 lowest in terms of density and diversity.

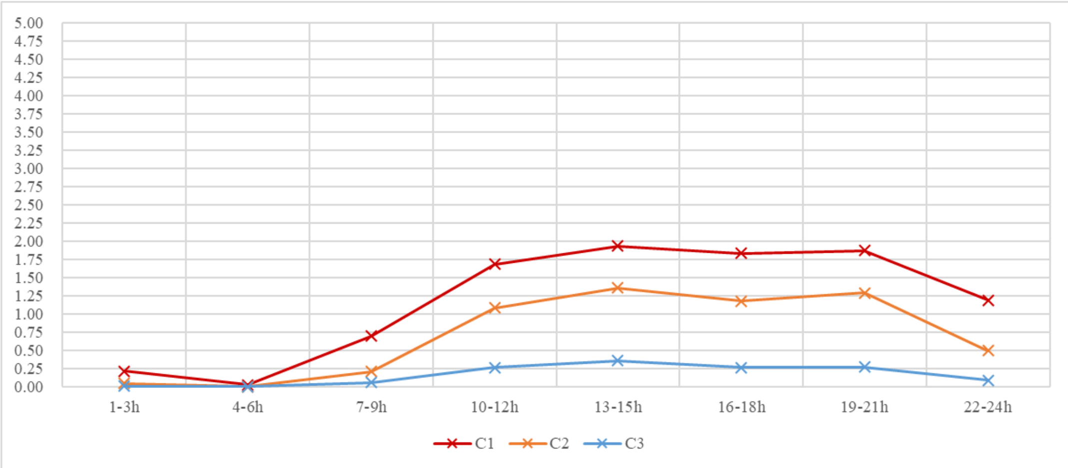
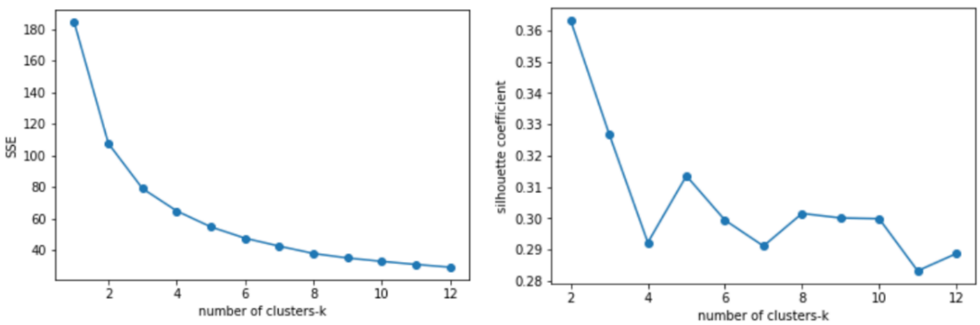


Fig 5.3-3 functional connectivity changing pattern of 3 clustering centers

In terms of functional connectivity changing with time, trends for Cluster1 and Cluster2 are quite similar, both at the lowest value in 4.00 to 6.00, increasing to relative high status after 10.00, where the fluctuation around peak value maintaining until 21.00 before the dropping appear. Data for Cluster1 and Cluster2 both reaches the summit at time period of 13.00 to 15.00, where the functional connectivity values are 1.93 and 1.36 respectively. By contrast, figure for Cluster3 has always remain at very low level, even in its peak hours between 13.00 and 15.00. (only 0.36)

2. Functional connectivity within 300m walk

Fig 5.3-4 illustrates the process of defining number of groups in clustering streets by change of functional connectivity within 300m walking distance. According to SSE map, number of clusters should be 3 (elbow at 3). This is validated by silhouette index map that the index peaks when number of clusters is 3.



(a) (b)

Fig 5.3-4 defining number of groups in clustering streets by change of functional connectivity within 300m walk: (a) SSE for the number of clusters from 1 to 12; (b) Silhouette index for the number of clusters from 2 to 12.

The result of clustering is shown in Fig 5.3-5. As is illustrated in the map, when considering 300m walking distance, the difference between two street areas increase, as most streets in San Babila fall in Cluster1 and most streets in China Town- Porta Nuova fall in Cluster3. It can be reasonably inferred that the difference between two streets areas lie in the capability of linkage with connected streets, for when considering single streets, the two areas are similar. Compared with clustering result of functional connectivity for single streets, the area of functional connectivity regions become bigger. For streets in San Babila, the main functional connectivity area is defined by border of Piazza del Duomo, Quadrilatero della Moda, and Sforzesco Castle Walls of the city. For streets in China Town- Porta Nuova, the main functional connectivity area is defined by Moscova - Arco di Porta Garibaldi - Porta Nuova and Piazza Gae Aulenti as well as some streets connected with Via Paolo Sarpi.

Fig 5.3-5 result of clustering in space

Line chart of Fig 5.3-6 visualizes the three clustering centers for functional connectivity within 300m walking distance. The changing pattern of functional connectivity in three clustering centers are same in that all the lines drop to lowest value for hours of 4.00 to 6.00, peak at time period of 13.00 to 15.00 and decrease after 21.00. For all three centers, functional connectivity remain at relatively high level between 10.00 and 21.00.

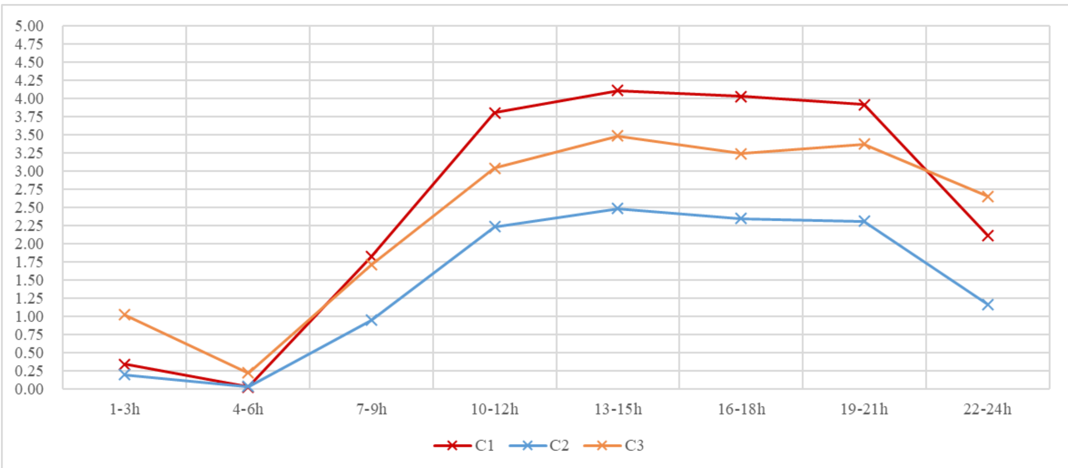


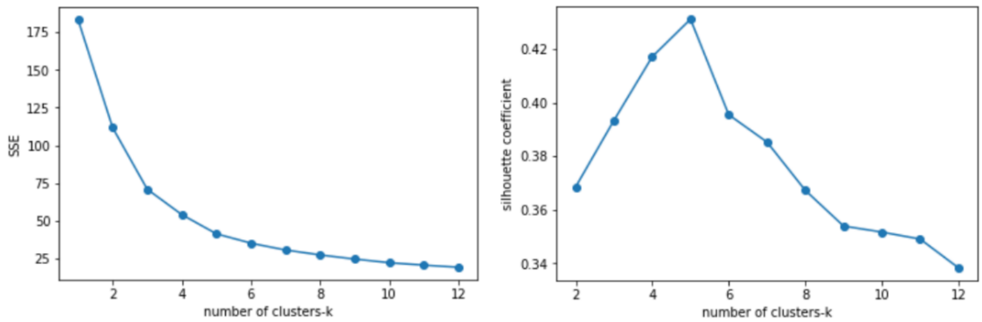
Fig 5.3-6 functional connectivity changing pattern of 3 clustering centers

Among the three clustering centers, Cluster2 has the least functional connectivity of all time. Cluster1 and Cluster2 share similar connectivity value between 7.00 and 9.00 (1.82 and 1.71 respectively), but data for Cluster1 goes above Cluster2 after 9.00 and stays in the lead until 21.00. Afterwards during night hours till 6.00, functional connectivity within 300m walking distance of Cluster1 is exceeded by data of Cluster2.

Compared with data within single streets, value of functional connectivity is significantly increased within 300m walking distance. This maybe caused by the fact that walking distance has made many streets which are low in density and diversity connected to the most active areas.

3. Functional connectivity within 500m walk

Fig 5.3-7 illustrates the process of defining number of groups in clustering streets by change of functional connectivity within 500m walking distance. As is shown in chart of SSE, the 'elbow' is not clear enough to decide number of clusters. But the silhouette index map has given unequivocal answer as data reaches the summit when the number of clusters is 5.



(a) (b)

Fig 5.3-7 defining number of groups in clustering streets by change of functional connectivity within 500m walk: (a) SSE for the number of clusters from 1 to 12; (b) Silhouette index for the number of clusters from 2 to 12.

Fig 5.3-8 result of clustering in space

Fig 5.3-8 shows the result of clustering by change of functional connectivity of streets within 500m walking distance spatially. With the increase of walking distance, the difference between the two street areas is further expanded: streets from San Babila and China Town- Porta Nuova fall in definitely different groups. In addition, the area of functional connectivity regions become bigger and form several continuous functional connectivity areas. For streets in San Babila area, 4 connectivity areas are found: first is Piazza del Duomo, Cordusio, Piazza San Babila and Quadrilatero della Moda in Cluster2; second is Brera in Cluster5; third is streets inside Sforzesco Castle Walls besides first and second areas in Cluster3; fourth is streets outside Sforzesco Castle Walls in Cluster1. For streets in China Town- Porta Nuova, 2 connectivity areas are detected, first is Moscova - Arco di Porta Garibaldi - Porta Nuova and Piazza Gae Aulenti in Group4; second is made up of the rest streets in Group5.

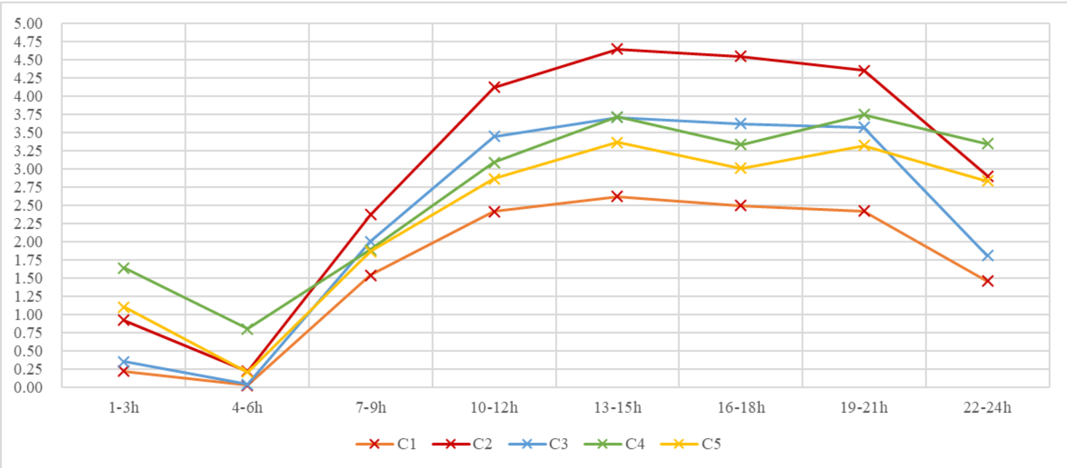


Fig 5.3-9 functional connectivity changing pattern of 5 clustering centers

In terms of functional connectivity changing with time, Fig 5.3-9 illustrates changing patterns of five kinds. The changing pattern of functional connectivity in five clustering centers are same in that all the lines drop to lowest value for hours of 4.00 to 6.00, peak at time period of 13.00 to 15.00 and decrease after 21.00.

To better understand the functional changing patterns, discussion is held on time period between 7.00 and 21.00 and time period between 21.00 and 7.00 next day respectively. Between 7.00 and 21.00 during the day, Cluster2 is the most connected, remaining at the highest level all the time; Cluster1 owns the least functional connectivity; whereas data for Cluster3, Cluster4 and Cluster5 stays in the middle during this time period. From 21.00 to 7.00 next day during the evening, Cluster1 and Cluster3 are similar as they both become the least active; data for Cluster2 and Cluster5 transfers to the middle. Cluster4, where the streets belong to Moscova - Arco di Porta Garibaldi - Porta Nuova and Piazza Gae Aulenti, though remains in the middle during the day, the functional connectivity becomes the highest in the evening.

5.4 Summary

In this part, functional changing patterns in general terms and their spatial distribution are summarized.

Generally speaking, the changing pattern of functional connectivity within single streets/ 300m walking distance/ 500m walking distance are of similar trend. Value of functional connectivity has always been at the bottom during 4.00 and 6.00 compared with other times of the day. After 7.00, functional connectivity of streets increase to a relatively high level between 10.00 and 12.00, nearly reaching the summit value between 13.00 and 15.00. The fluctuation around peak value continue until 21.00, when data of functional connectivity experiences a quick drop and back to the bottom.

Though sharing similar tendency, difference between clustered functional changing patterns is still obvious. Besides, with the enlargement of range in calculating functional connectivity, the functional changing patterns are also different. To be specific, a table (Tab 5.3-1) is given to summarize functional changing patterns in 3 dimensions by 'day-night' value format. In 'day-night' value format, 'day' means time periods from 7.00 to 21.00; 'night' means time periods between 21.00 and 7.00 next day. Value of functional connectivity is described by 'high', 'mid' and 'low' according to how they rank compared with other clustering centers.

Tab 5.3-1 functional changing pattern in general terms

Dimensions	Clusters	Functional Changing Patterns
functional connectivity within single streets	C1	high - high
	C2	mid – mid
	C3	low - low
functional connectivity within 300m walking distance	C1	high – mid
	C2	low – low
	C3	mid - high
functional connectivity within 500m walking distance	C1	low – low
	C2	high – mid
	C3	mid – low
	C4	mid - high
	C5	mid - mid

An alluvial diagram of cluster transformation across three different dimensions is given to show the relationship between different clustering processes (Fig 5.4-1). With the increase of walking distance, the number of isolated streets which are always in least functional connectivity is lessened.

Combined with space, from single streets to 300m walking distance, streets in China Town- Porta Nuova which in high- high mode all transform into mid- high pattern. Area of Galleria Vittorio Emanuele II- Cordusio, Piazza Filippo Meda, Piazza del Liberty and part of Corso Vittorio Emanuele II in high- high pattern expands to border of Piazza del Duomo, Quadrilatero della Moda, and Sforzesco Castle Walls of the city as high-mid pattern. Streets outside Sforzesco Castle Walls of the city stays always in the low-low pattern with the dimension changing.

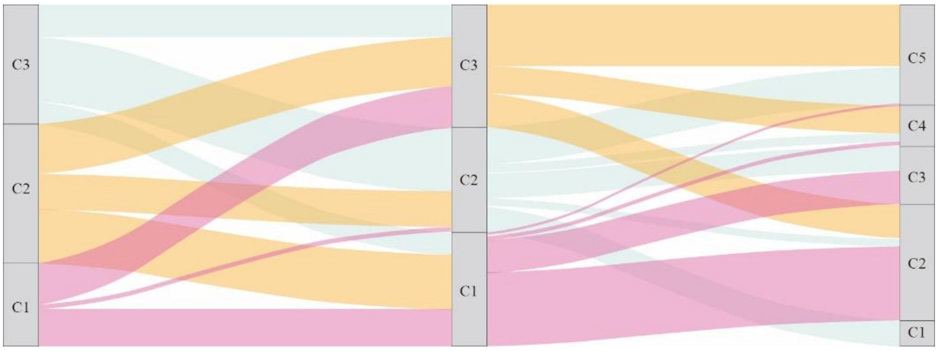


Fig 5.4-1 Alluvial diagram of cluster transformation across three different dimensions

From 300m walking distance to 500m walking distance, 500m walking distance make many streets in low-low mode going to more active patterns. At the same time, range of high- mid mode is also reduced because of the influence from transportation in places of original Sforzesco Castle Walls of the city. Area made by border of Piazza del Duomo, Quadrilatero della Moda, and Sforzesco Castle Walls of the city as high- mid pattern in 300m walking distance shift mainly to high- mid pattern with small numbers to mid-low pattern in 500m walking distance.

Chapter 6 Discovering Factors that Influence Functional Changing Pattern

In this chapter, factors that influence functional changing patterns are discussed from three aspects: first is focusing on different functional changing patterns of two street areas; second is focusing on different functional changing patterns from limited sense; third is focusing on different functional changing patterns in general terms. For first aspect, the general difference between two areas is discussed in qualitative ways; for second and third aspects, this research is selecting factors from Chapter 2 to verify if they really influence functional changing patterns in quantitative terms.

6.1 Factors that Influence Difference Between Two Study Areas

According to what is found in Chapter 4 and Chapter 5, area of San Babila and area China Town- Porta Nuova vary in functional changing patterns in both limited sense and general terms. This research is trying to analyze the difference from general difference; historic difference and policy difference in this part.

1. General difference

Though paying more attention to historic difference and policy difference, the general difference between the two street areas is still listed as follows:

In the first place, in terms of location, San Babila is in the center of Milan city, whereas China Town- Porta Nuova is at outer places, where the main traffic of inner city ring is located. According to agglomeration theory, central location usually attracts more people, which might explain the activeness of San Babila area; secondly, from perspective of the form of the two areas, San Babila is of planar structure but China Town- Porta Nuova is of lineal feature. Usually, it is considered planar structures are more conducive to expanding of commercial atmosphere. This is also validated by the fact that in concluded functional changing patterns, China Town and Porta Nuova are forming two centers respectively in most cases. Finally, though both of the study areas are providing mainly commercial services, the emphasis is different. Services provided in San Babila area are mainly shopping places, caterings, cafés, high-end boutiques and flagship shops. By contrast, commercial form in China Town are more related with local shops, groceries and other catering services. Porta Nuova area is quite different compared with the two because of the rich night lives. Besides, area around Piazza Gae Aulenti in Porta Nuova is providing special city life and city view with modern architectures.

2. Historic difference

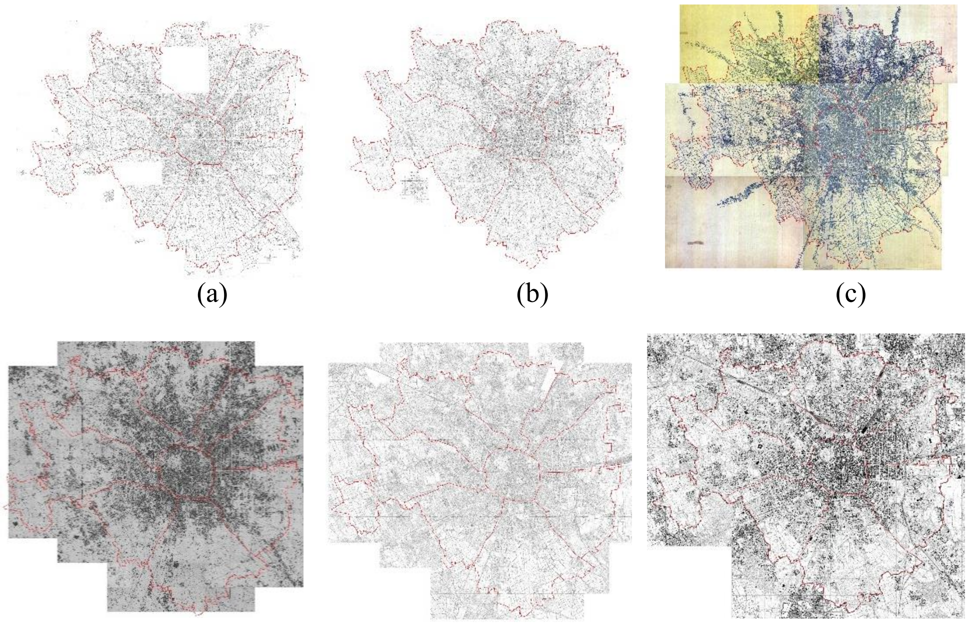
The two selected areas have been very different through historic revolution. This research is trying to study the historic difference from a geographic view by comparing various historic time city data from https://geoportale.comune.milano.it 1930 until 2018.

Fig 6.1-1 Beruto Masterplan 1884-1889. (Source: https://geoportale.comune.milano.it)

The city of Milan expanded vastly and transformed as a result from The Beruto Plan (Figure 6.1-1) – the first masterplan, especially contributing to the transformation of the city center, at that time still enclosed within the Spanish walls (1549-1560), which resembled as a place to represent the ideas of emerging Milanese bourgeoisie. Cesare Beruto used 'cautious and modest plan' techniques to express an international vision of the predicted expansion of the city. The new masterplan aimed to regulate the urban development and structure the growth beyond the Spanish walls, which experienced a complete demolishing process (except in some limited partitions).

The first signs for the urban growth were indicated by high integration and immersion of educational plots, religious temples and cultural grounds (theaters and other institutions), which were situated in the internal perimeter of the castle (Spanish) walls, embedded within the newly establishing residential areas, diffusing the borders of the primary fixation line (the castle walls). The vast urbanization and population growth led to the translation of high-density residential areas that surrounded the historical core as well. Despite the decadence of the wall function, the vigorous temper of the medieval city wall acquired its role as a ring-shaped fixation that outlined the further urban expansion.In addition, the plan concentrated on the multiplication of main transportation axes that connected the historic city core with the outlying districts, thus required for the implementation of an inner ring road pedestrian walkway, similar to the Vienna ring road saturated with parks, gardens, services and facilities, which mostly took place along the footprint of the once existing wall. Nevertheless, several key urban facilities for the further expansion of the city were founded and the structure that ordered the urban fabric was represented by the street grid.

The most evident portion of the Beruto plan concentrated on a "donut" like expansion, which varied in depth, between the Spanish walls and a new outer ring road that aimed to unite the few already developed areas beyond the walls. Another fundamental part of the Manifesto was the elongation of a north-west transportation artery that was generated by the extended area of the Castle and the newly designed Parco Sempione park, passing through Piazza del Duomo and the Galleria, it directed to the south-east to create a continuous axis, which required the demolishing of a limited portion of the urban fabric and renovation of few to reorganize a new urban system in the historical district.



(a) (b) (c)

(d) (e) (f)

Fig 6.1-2 city of Milan in various historic times (with 9 municipals):
(a) Milan 1930; (b) Milan 1946; (c) Milan 1956; (d) Milan 1972; (e) Milan 1990; (g) Milan 2018

Based on the Beruto Masterplan, Milan city experienced affirmation of the primary fixation line (the city wall), but defined new secondary fixation line, formed by the newly established transportation/railway ring. Land utilization characterized with low density residential districts, agricultural lands, hospitals, cemeteries, parks and recreational areas with sports features, military areas, industrial areas, marketplaces, college grounds and low-density villa estates. During this time period, area of China Town- Porta Nuova started to form but far different as function of present day (high density residential land use).

Since 1930 until 1972 according to Fig 6.1-2, vast expansion and new primary fixation line - the transportation/railway ring and a secondary fixation line - a new administrative boundary of the great city of Milan are observed. Land utilization pattern preserved constant features. Area of San Babila is preserved as historic core during this time period. Years from 1972 to 2018 defined consolidation features of the primary (railway ring) and secondary (administrative boundary) fixation lines. Transformation of area China Town- Porta Nuova from high density residential land use to consolidation of CBD finished in this period, which form situation of today.

In conclusion, the historic difference between San Babila and China Town- Porta Nuova is manifest in process of formation. To be specific, San Babila area has always been in core area of city within Spanish walls along the history with deep culture deposits.

3. Policy difference

This research is focusing on the Milan's car policy and congestion charge. In Milan, the car policy can be traced back to year 2008, when the Ecopass program was implemented as an urban tool for some vehicles driving within a traffic restricted zone or ZTL (Zona a Traffico Limitato) encircling 8.2km^2 within all the area of Cerchia dei Bastioni. It was implemented as a one-year experiment in January 2008 and was then extended until 2011. Only vehicles with high-polluting engines were charged and vehicles with the oldest and most polluting engines were banned. Depending on the vehicles' engine emissions standard, the fees varied from 2 to 10 euros on every weekday

In 2012, a new scheme (Area C)[7] was implemented, replacing the Ecopass system. Area C is based on the same area of the Ecopass system. Within Area C, every vehicle has to pay 5 euros regardless of their pollution level. The funds that would be raised from this program would allow the city to finance public transportation projects, cycle paths and green vehicles.

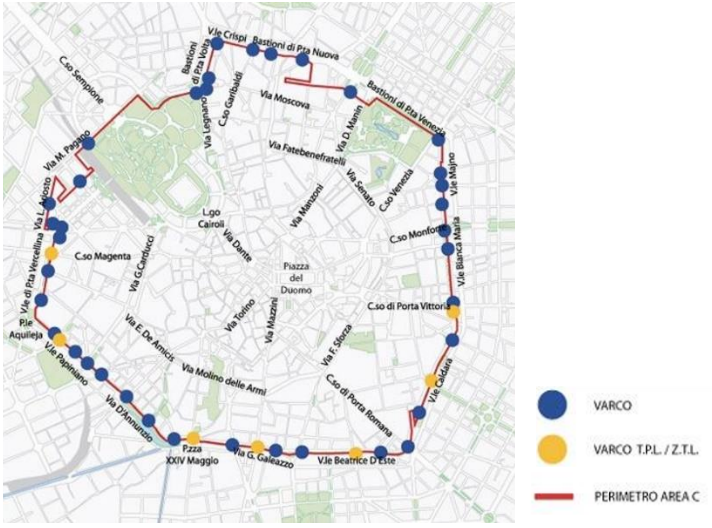


Fig 6.1-3 boundary of area C

(Source: https://www.comune.milano.it/aree-tematiche /mobilita/ area-c)

As is shown in Fig 6.1-3, the C area is a Zone of Limited Traffic called Cerchia dei Bastioni. It is delimitated by 43 gates with surveillance cameras, which 7 of them are exclusively for public transportation use (yellow dots on the map). In fact, 13 bus lines, 12 tram lines and 3 metro lines pass through the area, entering and exiting via some roads in the south of Milan.

Focusing on the two street areas, area C, which defined by the car policy and congestion charge to create walking atmosphere, has included San Babila and part of Porta Nuova area (from Moscova to Arco di Porta Garibaldi and Porta Nuova). China Town is excluded. This might explain why China Town and Porta Nuova are linked but very different in functional changing patterns

[7] https://www.comune.milano.it/aree-tematiche/mobilita/area-c

6.2 Selection of Factors for Further Verification

Chapter 2 has listed out and summarized possible factors that can influence functional changing patterns of street. According to the availability of data and exclusion of factors that are not working in the research scale, this research is selecting factors that are meaningful in further verification.

1. Indicators, supporting data and measurement

(1) People:

Local people:

local people are supposed to be main users of open spaces, Milan center area, which is known as most active, however, is not the choice local people. Fig 6.2-1 and Fig 6.2-2 show the population density and population growth rate of Milan municipality. From the view of population density, study area has thinner population density than outside areas; and they are also expecting smaller growth. This is because center area of Milan is not intended to serve people within the area, but serving people from whole municipality.

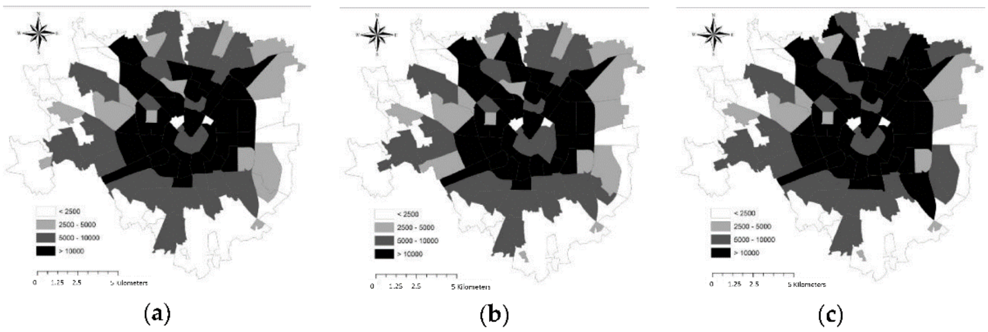


Fig 6.2-1 Population density in Milan municipality by urban district:
(a) 1999 real data; (b) 2017 real data; (c) 2036 forecast.

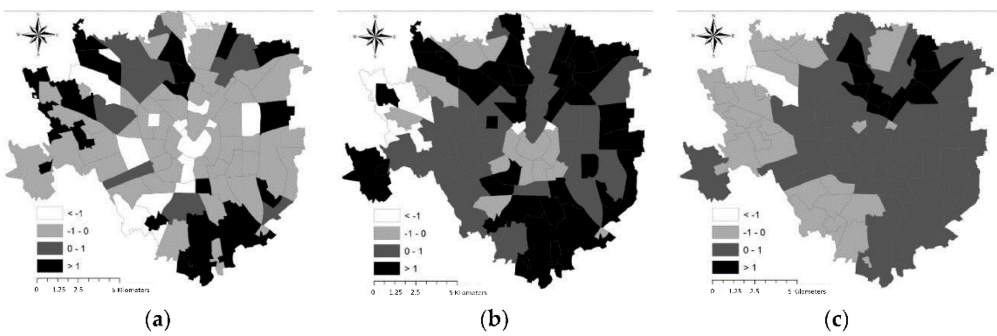


Fig 6.2-2 Annual population growth rate (%) in Milan municipality by urban district:
(a) 1999–2008 real data; (b) 2008–2017 real data; (c) 2017–2036 forecast.

Outsiders/ travelers:

It is reasonable to infer that people who really are continuously making functional changing of streets are outsiders and travelers. This view is also supported by the fact

Milan city center is not offering many residential land uses but supplying quantity of working places and job opportunities. Based on the mode of people's travelling behavior, schools, working places and hotels are considered to be source of people. Furthermore, it is also supposed that each street is attracting people directly nearby of 500m walking distance. Factors, indicators and measurement methods of people domain are concluded as Tab 6.2-1:

Tab 6.2-1 factors, indicators, supporting data and measurement of 'people' domain

Domains	**factors**	**indicators**	**supporting data and measurement**
people	density of people	density of outsiders	number of check-ins of schools/ working places on unit area
		density of travelers	number of check-ins of hotels on unit area
	diversity of people	diversity of outsiders/ travelers	entropy value of three kinds of people

(2) Activities:

'Activities' domain is following factors proposed in chapter 2.

Tab 6.2-2 factors, indicators, supporting data and measurement of 'activities' domain

Domains	**factors**	**indicators**	**supporting data and measurement**
activities	Mixed function intensity	density of services	number of supplied services on unit area
		diversity of services	entropy of 10 kinds of supplied services
	Business Ratio	percentage of supplied shopping places	number of supplied shopping places divided by number of supplied services
	Accessibility of daily services	density of daily services	number of supplied daily services on unit area

(3) Physical environment

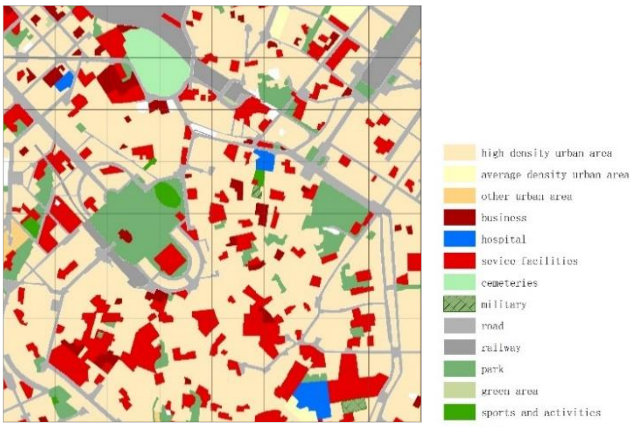


Fig 6.2-3 land use of study area (data from DUSAF[8]; grid: 500m)

Existing researches have supplied plenty means to quantify the physical environment. According to the accessibility of data, this dissertation is selecting several factors with indicators, supporting data and measurement are chosen to see how the streets in the

[8] https://www.regione.lombardia.it/

same group are alike.

From perspective of city-based view, land use diversity is excluded because development of the city has made Milan center area into a highly mixed and relatively ‘homogeneous’ area. (Fig6.2-3) Hence the factors for physical environment are focused more on pedestrian-based perspective with only ‘transportation’ for city perspective.

Transportation:

For transportation, 5 kinds of public transportation data are acquired besides the network of roads to analyze the transportation system: metro lines and stations (Fig 6.2-4 (a)); bus lines and mini train lines (Fig 6.2-4 (b)(c)); bicycle lanes (Fig 6.2-4 (d)) and sharing points for cars and bicycles (Fig 6.2-4 (e)). The study area has developed similar mode of transportation with mixed transportation for most area with only small numbers in pedestrian only. In calculation of diversity of means of public transport, this research is combining bus lines and mini train lines together for they are of similar mode in running. Additionally, density of bus and mini train lines are considered rather than number of stations because many lines are sharing the same stations, which means lines describe frequency of service better. Similarly, the metro system is only considering accessible stations because lines underground is not serving people actually.

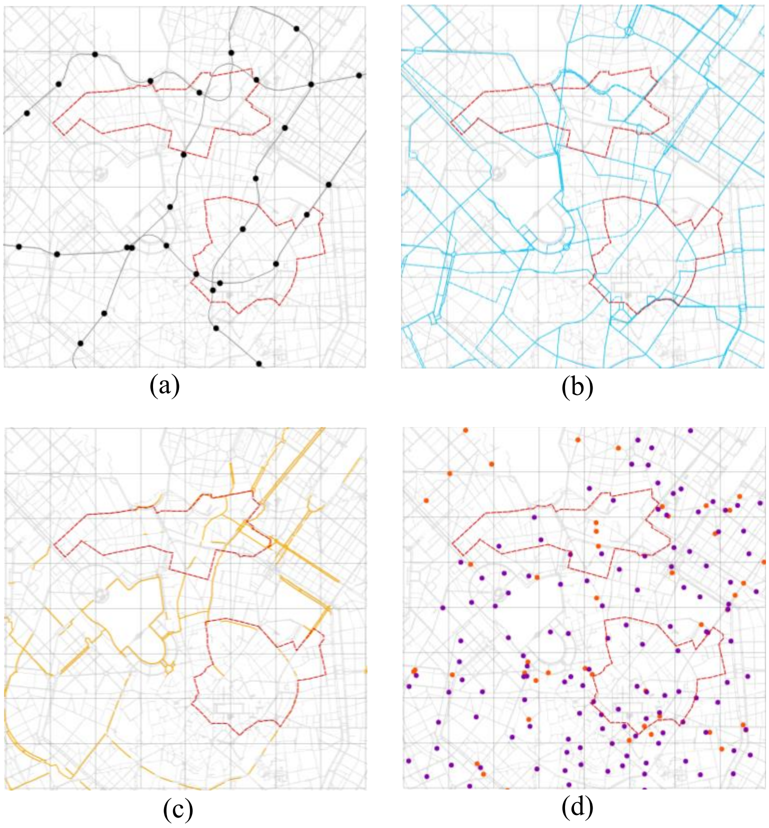


Fig 6.2-4 means of transportation:
(a) metro lines and stations; (b) bus lines and tram lines; (c) bicycle lanes; (d) sharing points for cars and bicycles (purple: bicycle sharing points; orange: car sharing points) (grid: 500m)

Urban form:

Interface density and sky view factor (SVF) are used to describe urban form. Interface density describes the street from the perspective of the relationship between the building facades and the streets; whereas SVF describes the street from the perspective of the relationship between the sky façade and the streets.

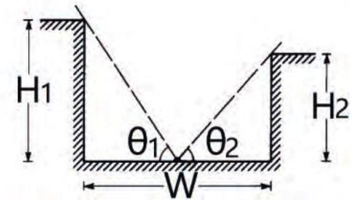


Fig 6.2-5 calculation of SVF:
H = height of building façade; W = width of street; θ = elevation angle

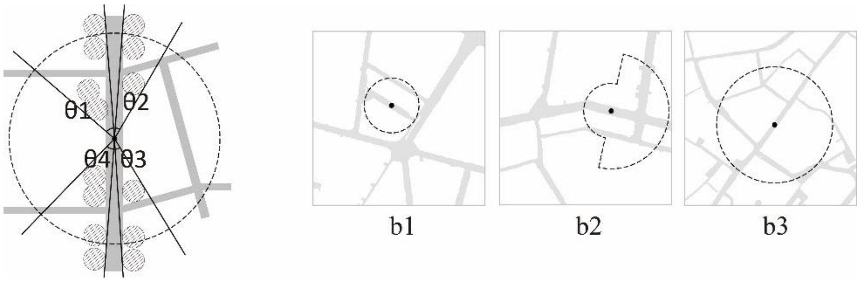
Calculation of SVF is shown as follows, meaning of variables in Fig 6.2-5

$$\varphi_{\mathrm{SVF}} = \frac{\pi - \theta_1 - \theta_2}{\pi} \tag{1}$$

Where: $\theta = \tan^{-1}(H/0.5W)$

Spatial cognition:

Indicators of D/H and green vision ratio are chosen to describe spatial cognition of streets. In terms of green vision ratio, eye-level green vision ratio is applied in this dissertation instead of seeing human's field of vision as a dome.



(a) (b)

Fig 6.2-6 calculation of eye-level green vision:
(a) θ = vision angles that can see 'greens'; (b) three conditions of vision

To be specific, calculation formula of eye-level green vision is as follows, meaning of variables in Fig 6.2-6 (a):

$$\varphi_{\mathrm{GV}} = \frac{\pi - \theta_1 - \theta_2 - \cdots \theta_n}{\pi} \tag{2}$$

Fig 6.2-6 (b) shows three conditions of vision on streets. Range of vision is furthest to 300 m. Eye-level green vision is based on people's sight, which means in Fig b1, when the sight is blocked, the range's diameter is equal to the length of road; in Fig b2, when the sight is blocked by inflection of road, the front and back ranges of vision are different; in Fig b3, the sight is not blocked by nothing, the range of vision is as far as

500m.

Environment behavior:

Indicator of density of street furniture is taken for environment behavior. Street furniture in this part is specifically referred to furniture that serve people. In this sense, installation like rubbish bins and surveillance cameras are excluded whereas small facilities such as florist stands; kiosks; news agencies; vending machines are included.

Factors, indicators and measurement methods of physical environment domain are concluded as Tab 6.2-3

Tab 6.2-3 factors, indicators, supporting data and measurement of ‘physical environment’ domain

Domains	**factors**	**indicators**	**supporting data and measurement**
physical environment	transportation	public transportation connection	density of bus and tram lines in unit area;
			average distance to nearest metro stations;
		other means of transportation	density of bicycle lanes;
			density of sharing points;
		network density	meters of roads in unit area;
	urban form	Interface density	ratio of the total projection surface width of a building (including fences and fences) with the length of the street or road on one side of a certain section of a street
		Sky view factor, SVF	SVF formula (x)
	spatial cognition	H/D	ratio of the height of buildings along the street to street width (in case for some streets, the height of facades is 0)
		Green vision ratio	GV formula (x)
	environmental behavior	Street furniture	number of street furniture on unit area

(4) Social environment

Indicators for factors in social environment domain are not defined clearly in existed studies. Still, this research is defining indicators for safety and landmarks to compare the similarities of streets. For safety, this research is using density of night services as indicator for the reason that during daytime, the study area is generally of high safety level because of intense usage. For landmarks, check-in data of Foursquare has shown that people are highly accumulating in open spaces (squares and parks). Similar phenomenon can be found also in check-ins on tourist attractions. Indicators and supporting calculation are shown in Tab 6.2-4.

Tab 6.2-4 factors, indicators, supporting data and measurement of ‘social environment’ domain

Domains	**factors**	**indicators**	**supporting data and measurement**
Social	safety	density of night services	density of supplied services on unit area

environment	landmarks	accessibility to squares/ parks	average distance to nearest squares/ parks
		accessibility to tourist attractions	average distance to nearest tourist attractions

2. Summary

After selection, 20 factors in 4 domains are chosen to verify in the following part. Factors are summarized in Tab 6.2-5:

Tab 6.2-5 factors chosen to be verified in people, activities, physical environment and social environment domains:

Domains	**factors**	**data for verification**	**code**
people	density of people	density of outsiders	1
		density of travelers	2
	diversity of people	diversity of outsiders/ travelers	3
activities	Mixed function intensity	density of services	4
		diversity of services	5
	Business Ratio	percentage of supplied shopping places	6
	Accessibility of daily services	density of daily services	7
physical environment	transportation	density of bus and tram lines in unit area;	8
		average distance to nearest metro stations;	9
		density of bicycle lanes;	10
		density of sharing points;	11
		network density	12
	urban form	Interface density	13
		Sky view factor, SVF	14
	spatial cognition	H/D	15
		Green vision ratio	16
	environmental behavior	Street furniture	17
Social environment	safety	density of night services	18
	landmarks	accessibility to squares/ parks	19
		accessibility to tourist attractions	20

6.3 Factors that Influence Functional Changing Patterns (from Limited Sense)

In functional changing pattern from limited sense which is paying attention to what is happening on each street, distribution of activated functional points in specific time periods seems to influence the functional changing patterns more than factors proposed above. However, this research is still verifying the 20 proposed factors by comparing the features of the spatial distribution of the factors with if the streets are vibrant.

1. People

(a) (b) (c)

Fig 6.3-1 visualization of factors in ‘people’ domain:

(a) density of outsiders (people/ha); (b) density of travelers (people/ha); (c) diversity of outsiders/ travelers (--)

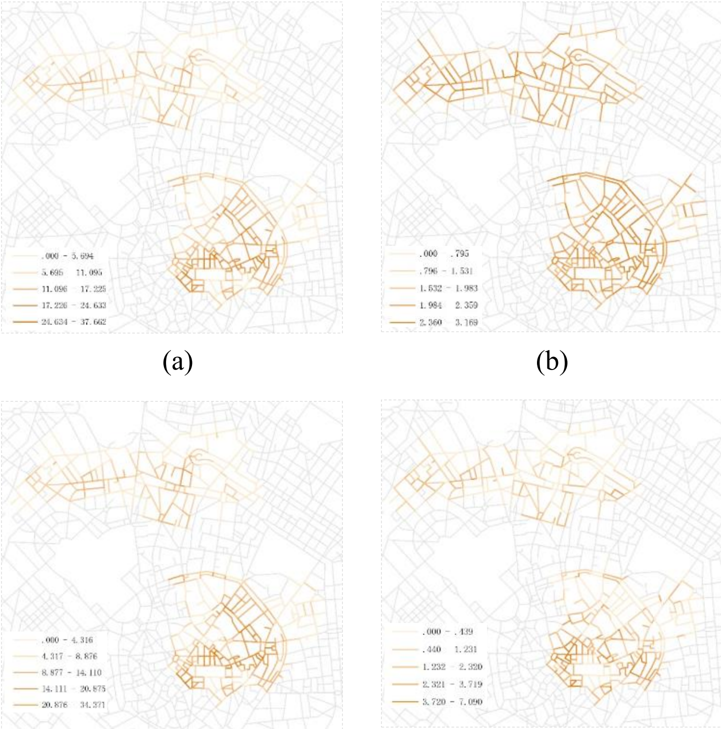
Fig 6.3-1 has shown spatial features of the three factors in ‘people’ domain. In terms of density of people, San Babila in city center generally has more people concentration than area China Town- Porta Nuova. Outsiders (students and working people) are mainly concentrated in southeast of Piazza San Babila, Largo Ildefonso Schuster and Brera. Second densest streets are found in Cordusio to Piazza del Duomo. Travelers are mainly accumulated in Monument to Leonardo da Vinci and Piazza del Liberty- Piazza San Babila. By contrast, the highest diversity of people is observed differently from density of outsiders and travelers in Quadrilatero della Moda, Galleria Vittorio Emanuele II and streets in Piazza Gae Aulenti and Porta Nuova.

Compared with functional changing patterns from limited sense, density of outsiders is not affecting the vibrancy of selected streets but by contrast, density of travelers is affecting the continuous activities of streets as they have more time moving around. Besides, diversity of outsiders/ travelers is also affecting the accumulation of people especially in high vibrancy hours.

2. Activities

Situation of density of services, diversity of services, percentage of supplied shopping places and density of daily services have been shown in Fig 6.3-2. Generally speaking, distributions of density of services, percentage of supplied shopping places and density of daily services are similar because of variation in space. Distribution of density of services and percentage of shopping places are sharing concentration within the old city wall as well as in Moscova- Piazza Gae Aulenti and Via Paolo Sarpi. This is in accordance with places that are in high vibrancy during busiest hours. In density of daily services, however, distribution variation in space mainly lie in difference between the two research areas, as area San Babila has apparently higher density of daily services compared with China Town- Porta Nuova, which can explain why streets in San Babila can be distinguished by daily services during clustering.

What is unexpected is that the two research areas are relatively uniform in terms of diversity of services except streets outside the old city wall. This can explain why streets outside old city wall are always among the least active clusters.



(a) (b)

(c) (d)

Fig 6.3-2 visualization of factors in ‘people’ domain:

(a) density of services (/ha); (b) diversity of services (--); (c) percentage of supplied shopping places (%); (d) density of daily services (/ha)

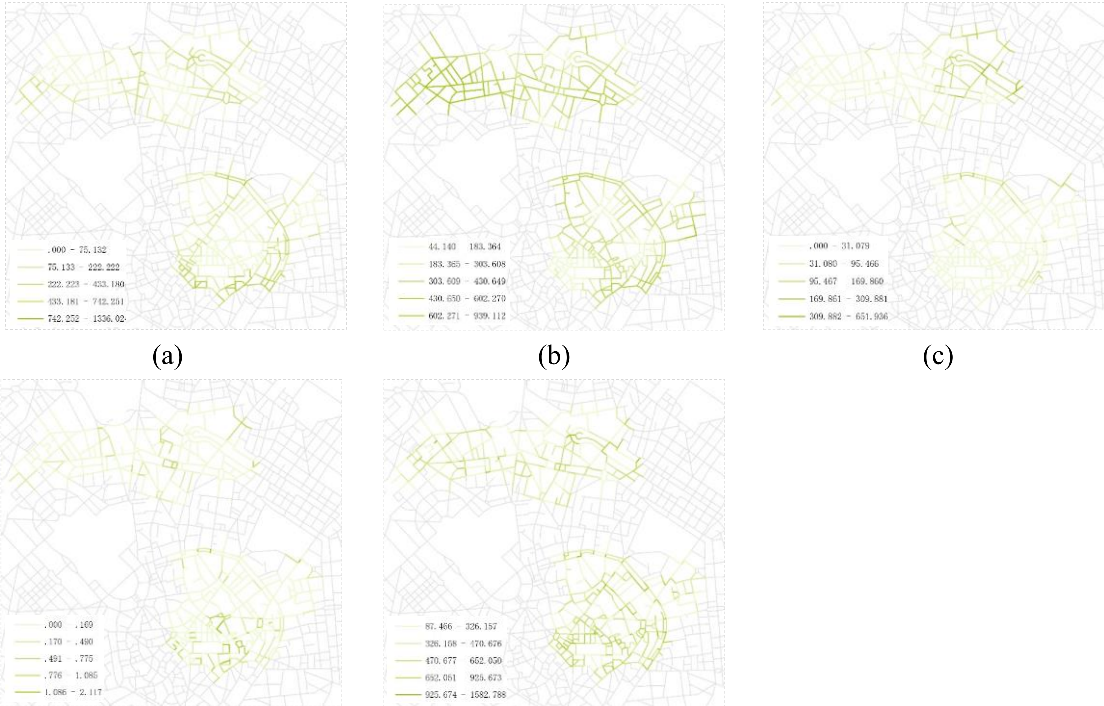
3. Physical environment

(1) Transportation

Transportation is discussed by five parts in this research, namely density of bus and tram lines, distance to nearest metro station, density of bicycle lanes, density of bike/car sharing points and network density (Fig 6.3-3). Variation in space is manifest in all indicators. Transportation mode has divided out several transportation belt and transportation area.

Several places that are distinctive across all indicators are listed as follows. Firstly, belt along the old city wall is observed with high density of bus and tram lines, far distance to nearest metro stations and high density of bicycle lanes. Also, this belt is of high density of network. Second is area in Porta Nuova- Piazza Gae Aulenti. This area is distinguished by relatively high value in density of bus and tram lines, density of bicycle lanes and density of network. Other belts include Cordusio- Giardini Pubblici Indro Montanelli and Parco Sempione- Cimitero Monumentale which are both main bus/tram belts. Belt from Monument to Leonardo da Vinci to Brera and area Via Paolo Sarpi are distinguished by far distance to metro stations.

Divided by the areas and belts mentioned above, the rest areas are of high density of bike/car sharing points and density of network, which are also in high vibrancy value in functional changing patterns.



(a) (b) (c)

(d) (e)

Fig 6.3-3 visualization of factors in 'physical environment' domain- transportation:
(a) density of bus and tram lines (m/ha); (b) distance to nearest metro station (m); (c) density of bicycle lanes (m/ha); (d) density of bike/car sharing points (/ha); (e) network density (m/ha)

(2) Urban form

The whole research area can be divided into four different kinds according to feature of urban form (Fig 6.3-4). China Town, Moscova and streets outside old city wall are of high interface density and low SVF, which is contrary to situation in Porta Nuova-Piazza Gae Aulenti. Streets inside the city wall are of very high interface density. Among them, streets in Quadrilatero della Moda are having low SVF but other streets are having relatively higher SVF for the successive squares.

Combined with functional changing patterns, higher interface density is accumulating more people during day time but during night hours, high SVF is attracting more people when many shops have closed.

(a) (b)

Fig 6.3-4 visualization of factors in 'physical environment' domain- urban form:
(a) Interface density; (b) SVF

(3) Spatial cognition

In human-oriented perspective, people's cognition of space has been considered to influence people's behavior in space. However, data of factors in spatial cognition has shown a different story (Fig 6.3-5), especially in green vision ratio. From the image, it is manifest that only streets outside the city wall and in Moscova- Porta Nuova rank high in green vision, which is verified as no relationship with functional changing patterns from limited sense.

(a) (b)

Fig 6.3-5 visualization of factors in 'physical environment' domain- spatial cognition

(a) H/D; (b) green vision ratio

(4) Environmental behavior

Areas that of high value in density of street furniture are concentrated around Piazza del Duomo and Piazza San Babila, with a small area in Arco di Porta Garibaldi (Fig 6.3-6). These areas are considered to have extreme vibrancy in all time periods.

Fig 6.3-6 visualization of factors in 'physical environment' domain- environmental behavior (density of street furniture (/ha))

4. Social environment

Night services have largely defined the vibrancy of streets during night hours according to Fig 6.3-7 (a), especially for areas with highest density of night services. In terms of landmarks, distance to open spaces is in negative correlation with accumulation of people. Streets that are furthest to open spaces are among the least active streets during the whole day (streets outside the old city wall and Via Gaetano de Castillia). Different from distribution of distance to nearest open spaces, distance to nearest attractions define out the most active streets around Piazza del Duomo, in Quadrilatero della Moda and Arco di Porta Garibaldi.

(a) (b) (c)

Fig 6.3-7 visualization of factors in 'social environment' domain

(a) density of night services (/ha); (b) distance to nearest open spaces (m); (c) distance to nearest attractions (m)

5. Summary

The functional changing patterns from limited sense are related with functional points by offering specific products/services at specific time periods as mentioned in Chapter 4. Through the analysis of distribution features, however, it is found that the functional changing patterns are result of combination of multiple proposed factors in four dimensions besides distribution of functional points.

Several factors are examined as not strongly related with functional changing patterns, namely, density of outsiders and green vision ratio. Outsiders are usually 'static' in space as they study or work in the place. Green vision ratio is more defined by the width of the road and the construction age of the area, both can attract people.

Most of the proposed factors influence functional changing patterns by defining if the streets are vibrant during the day, including density of travelers, diversity of people, factors in 'activities' domain, interface density, H/D and distance to nearest open spaces.

Two kinds of factors have affected functional changing patterns into distinctive features, the first kind is defining the high vibrancy during peak hours and the other is defining the accumulation of people during evenings. Specifically, factors from 'transportation' domain and distance to nearest attractions are providing people with impressive walking experience during the day, which cause the high vibrancy during day hours; whereas the sky view factor, density of street furniture and density of night services are influencing the vibrancy of streets during the night by providing services and places to stay after most services have stopped in the evenings.

6.4 Factors that Influence Functional Changing Patterns (in General Terms)

The process of verification is conducted by dimensions according to how the functional changing patterns are concluded in Chapter 5 as: functional connectivity within streets; functional connectivity within 300m walking distance; functional connectivity within 500m walking distance.

Method used is non-parametric test as confirmed in Chapter 3. The null hypothesis is distribution of the supposed factors are the same for different clusters. If the decision retains the null hypothesis, it means for the specific factor, difference between groups is not manifest; whereas if the decision rejects the hypothesis, the difference is statistically manifest. For factors that reject the null hypothesis, further discussion of pairwise comparisons between clusters are given where links with orange lines mean the difference is manifest; whereas black lines mean no difference.

1. functional connectivity within streets

As is shown in hypothesis test summary (Tab 6.4-1), among the 20 listed factors supposed to be related with functional changing patterns, 5 factors are verified as not affecting the changing patterns: density of outsiders; density of bus and tram lines in unit area; density of sharing points; network density and Sky view factor (SVF).

Tab 6.4-1 hypothesis test summary for functional connectivity within streets

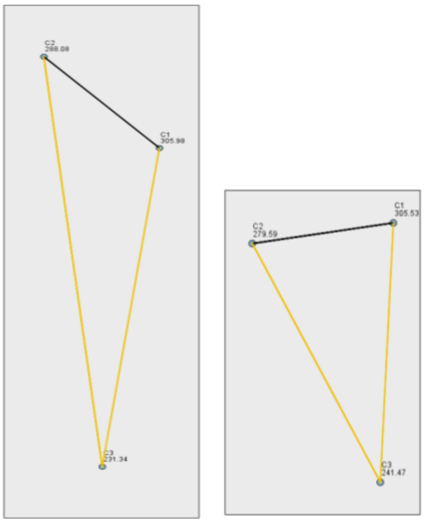
Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of P_outsiders_density is the same across categories of CLUSTER.	Independent-Samples Kruskal-Wallis Test	.588	Retain the null hypothesis.
2	The distribution of P_travellers_density is the same across categories of CLUSTER.	Independent-Samples Kruskal-Wallis Test	.000	Reject the null hypothesis.
3	The distribution of P_diversity is the same across categories of CLUSTER.	Independent-Samples Kruskal-Wallis Test	.001	Reject the null hypothesis.
4	The distribution of A_density is the same across categories of CLUSTER.	Independent-Samples Kruskal-Wallis Test	.000	Reject the null hypothesis.
5	The distribution of A_diversity is the same across categories of CLUSTER.	Independent-Samples Kruskal-Wallis Test	.000	Reject the null hypothesis.
6	The distribution of A_retail_catering is the same across categories of CLUSTER.	Independent-Samples Kruskal-Wallis Test	.000	Reject the null hypothesis.
7	The distribution of A_daily_service is the same across categories of CLUSTER.	Independent-Samples Kruskal-Wallis Test	.000	Reject the null hypothesis.
8	The distribution of PE_bustram_density is the same across categories of CLUSTER.	Independent-Samples Kruskal-Wallis Test	.646	Retain the null hypothesis.
9	The distribution of PE_to_metro is the same across categories of CLUSTER.	Independent-Samples Kruskal-Wallis Test	.003	Reject the null hypothesis.
10	The distribution of PE_bike_lane_density is the same across categories of CLUSTER.	Independent-Samples Kruskal-Wallis Test	.013	Reject the null hypothesis.
11	The distribution of PE_sharing_points_density is the same across categories of CLUSTER.	Independent-Samples Kruskal-Wallis Test	.465	Retain the null hypothesis.
12	The distribution of PE_road_density is the same across categories of CLUSTER.	Independent-Samples Kruskal-Wallis Test	.678	Retain the null hypothesis.
13	The distribution of PE_interface_density is the same across categories of CLUSTER.	Independent-Samples Kruskal-Wallis Test	.030	Reject the null hypothesis.
14	The distribution of PE_sky_view_factor is the same across categories of CLUSTER.	Independent-Samples Kruskal-Wallis Test	.139	Retain the null hypothesis.
15	The distribution of PE_h_d is the same across categories of CLUSTER.	Independent-Samples Kruskal-Wallis Test	.035	Reject the null hypothesis.
16	The distribution of PE_green_vision is the same across categories of CLUSTER.	Independent-Samples Kruskal-Wallis Test	.000	Reject the null hypothesis.
17	The distribution of PE_urban_furniture_density is the same across categories of CLUSTER.	Independent-Samples Kruskal-Wallis Test	.000	Reject the null hypothesis.
18	The distribution of SE_safety is the same across categories of CLUSTER.	Independent-Samples Kruskal-Wallis Test	.000	Reject the null hypothesis.
19	The distribution of SE_to_attraction is the same across categories of CLUSTER.	Independent-Samples Kruskal-Wallis Test	.021	Reject the null hypothesis.
20	The distribution of SE_to_openspace is the same across categories of CLUSTER.	Independent-Samples Kruskal-Wallis Test	.000	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

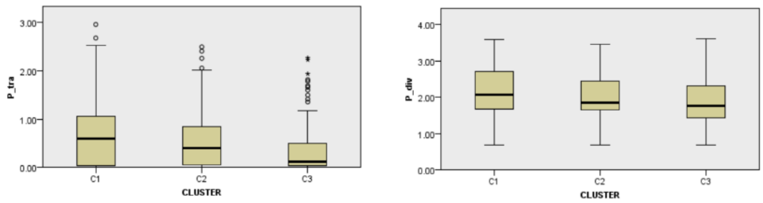
(1) People:

From domain of people, outsiders are not defining streets, but travelers and diversity of three kinds of people. As shown in Fig 6.4-1, it is obvious that difference between three clusters lie in the difference between Cluster3 (low-low pattern) and the other two. Clusters of high-high pattern and mid-mid pattern are having far higher density of travelers and higher diversity of people compared with Cluster3 (Fig 6.4-2).



(a) (b)

Fig 6.4-1 pairwise comparisons between clusters: (a) density of travelers; (b) diversity of people

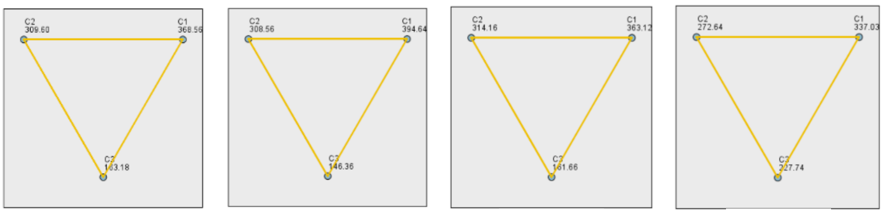


(a) (b)

Fig 6.4-2 independent sample Kruskal Wallis test:(a) density of travelers; (b) diversity of people

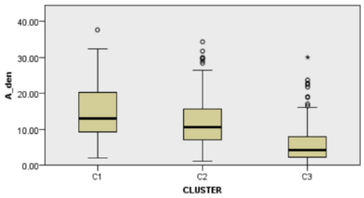
(2) Activities:

Factors in ‘activities’ domain are distinguishing streets into three groups (Fig 6.4-3). Combined with result of independent sample test, distribution of density of services is highest as a whole for high-high pattern, in terms of minimum, maximum and median value; in the middle for mid-mid pattern; and lowest for low-low pattern. Same kind of law is also found for diversity of services; percentage of supplied shopping places and density of daily services.

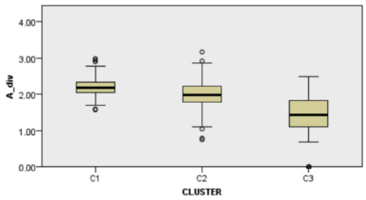


(a) (b) (c) (d)

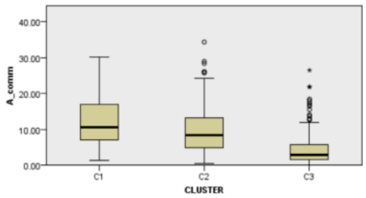
Fig 6.4-3 pairwise comparisons between clusters: (a) density of services; (b) diversity of services; (c) percentage of supplied shopping places; (d) density of daily services



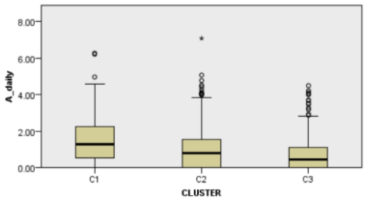
(a)



(b)



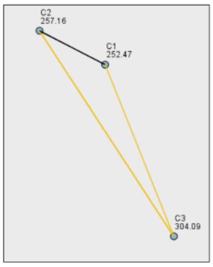
(c)



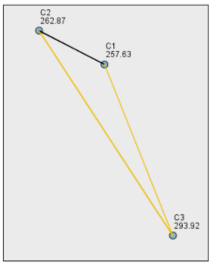
(d)

Fig 6.4-4 independent sample Kruskal Wallis test: (a) density of services; (b) diversity of services; (c) percentage of supplied shopping places; (d) density of daily services

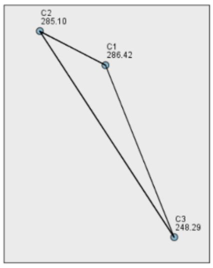
(3) Physical environment:



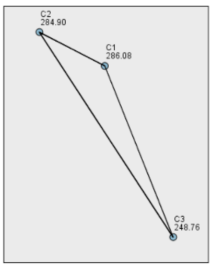
(a)



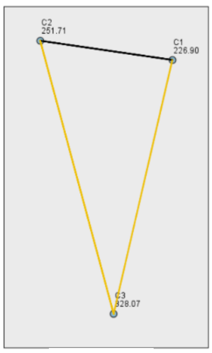
(b)



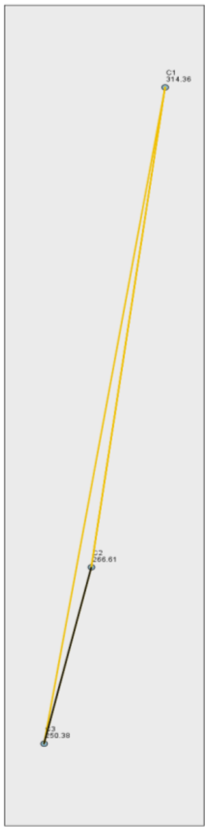
(c)



(d)



(e)



(f)

Fig 6.4-5 pairwise comparisons between clusters: (a) distance to nearest metro station; (b) density of bicycle lanes; (c) Interface density; (d) H/D; (e) Green vision ratio; (f) Street furniture

In terms of transportation, only distance to the nearest metro station and density of bicycle lanes make difference between Cluster3 (low-low pattern) and the other two (Fig 6.4-5, Fig 6.4-6). For distance to nearest metro stations from segment nodes, streets belonging to Cluster3 (low-low pattern) are further to the nearest station compared with streets in other two clusters. For density of bicycle lanes, it is interesting that streets in

Cluster3 have more bicycle lanes, from which it can be inferred that bicycle lanes might make less people staying on streets.

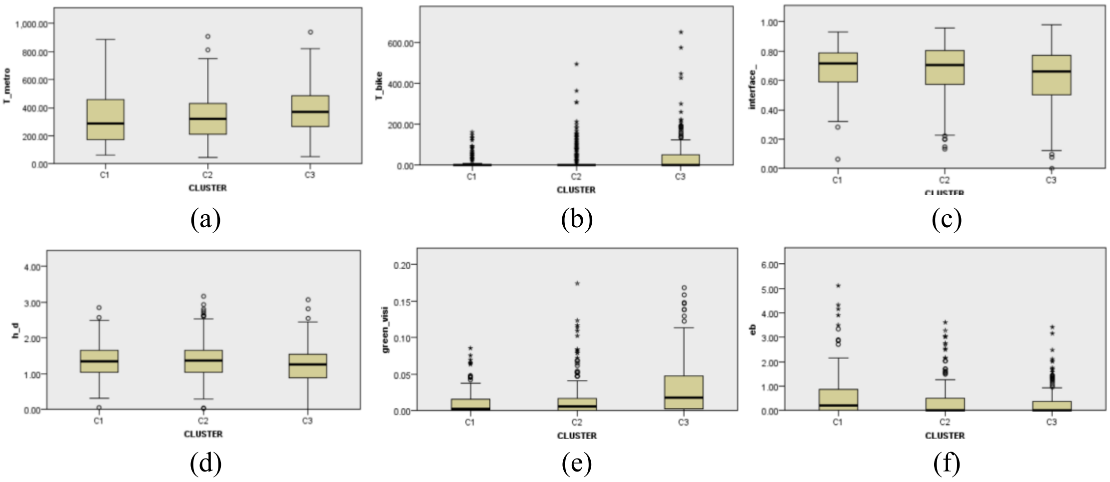


Fig 6.4-6 independent sample Kruskal Wallis test: (a) distance to nearest metro station; (b) density of bicycle lanes; (c) Interface density; (d) H/D; (e) Green vision ratio; (f) Street furniture

As verification for urban form, spatial cognition and environmental behavior, interface density, H/D, green vision ratio and street furniture are considered to have influence the functional changing pattern classification according to hypothesis test summary. However, pairwise comparisons have proved that for interface density and H/D, the difference between three clusters is not statistically significant (Fig 6.4-5 (c)(d)). As for factor of green vision ratio, what is unexpected is that Cluster3 is special in its high green vision ratio compared with other two. In comparison of street furniture, the mid-mid pattern and low-low pattern are quite similar with very small number of street furniture whereas by contrast, streets in Cluster1 (high-high mode) are having far more street furniture (Fig 6.4-6 (e)(f)).

(4) Social environment

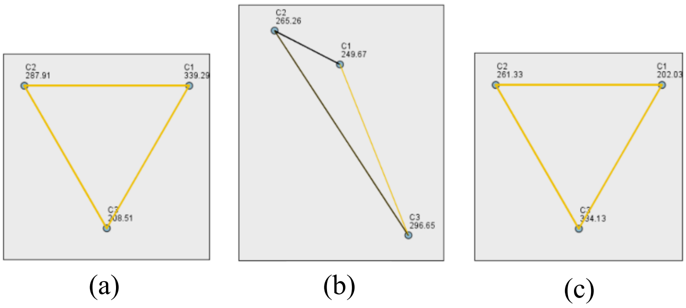
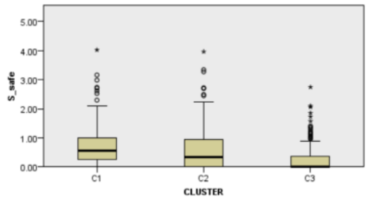
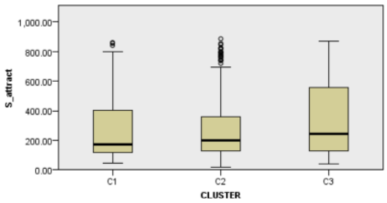


Fig 6.4-7 pairwise comparisons between clusters: (a) density of night services; (b) accessibility to tourist attractions; (c) accessibility to squares/ parks

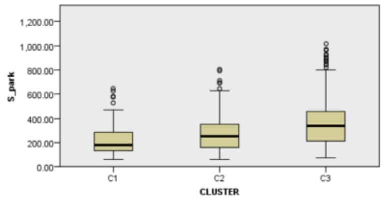
Factors in social environment are all separating streets into different groups (Fig 6.4-7). Among them, factors calculated in density of night services and accessibility to squares are validated as different throughout the three clusters. To be specific, combining result of independent sample test, streets belonging to high-high pattern are having highest density of night services; mid-mid pattern in the middle and low-low pattern having the lowest. This kind of correspondence in stepped types is also found in accessibility to open spaces but inversed: highest in low-low mode; lowest for high-high mode and mid-mid mode in the middle.



(a)



(b)



(c)

Fig 6.4-8 independent sample Kruskal Wallis test: (a) density of night services; (b) accessibility to tourist attractions; (c) accessibility to squares/ parks

Accessibility to tourist attractions is quite special compared with other two factors in 'social environment' domain for the difference is detected as manifest for Cluster1(high-high pattern) and Cluster3 (low-low pattern). Streets in Cluster1 are far nearer to tourist attractions compared with streets in Cluster3.

(5) Summary:

To sum up, factors from four defined domains are influencing the functional changing patterns as supposed after the process of verification, but most of the factors vary only between Cluster1 (high-high pattern) and others or vary only between Cluster3 (low-low pattern). Only six factors are distinguishing streets into three groups: density of services; diversity of services; percentage of supplied shopping places; density of daily services; density of night services and accessibility to squares/ parks.

2. functional connectivity within 300m walking distance

According to the hypothesis test summary in Tab 6.4-2, all the proposed factors are influencing the classification of streets, except density of bus and tram lines in unit area. This is quite different from the universal cognition as public transportation can bring crowds of people and stimulate economic vitality nearby. This research is inferring that although the two selected areas have difference in location, they are all in the center of Milan city if they are viewed in bigger scale. Public transportation is density enough in general 'city center' to make the study area same. Other factors that have rejected the null hypothesis are discussed as follows:

Tab 6.4-2 hypothesis test summary for functional connectivity within 300m walking distance

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of P_outsiders_density is the same across categories of CLUSTER.	Independent-Samples Kruskal-Wallis Test	.000	Reject the null hypothesis.
2	The distribution of P_travellers_density is the same across categories of CLUSTER.	Independent-Samples Kruskal-Wallis Test	.000	Reject the null hypothesis.
3	The distribution of P_diversity is the same across categories of CLUSTER.	Independent-Samples Kruskal-Wallis Test	.000	Reject the null hypothesis.
4	The distribution of A_density is the same across categories of CLUSTER.	Independent-Samples Kruskal-Wallis Test	.000	Reject the null hypothesis.
5	The distribution of A_diversity is the same across categories of CLUSTER.	Independent-Samples Kruskal-Wallis Test	.000	Reject the null hypothesis.
6	The distribution of A_retail_catering is the same across categories of CLUSTER.	Independent-Samples Kruskal-Wallis Test	.000	Reject the null hypothesis.
7	The distribution of A_daily_service is the same across categories of CLUSTER.	Independent-Samples Kruskal-Wallis Test	.000	Reject the null hypothesis.
8	The distribution of PE_bustram_density is the same across categories of CLUSTER.	Independent-Samples Kruskal-Wallis Test	.193	Retain the null hypothesis.
9	The distribution of PE_to_metro is the same across categories of CLUSTER.	Independent-Samples Kruskal-Wallis Test	.000	Reject the null hypothesis.
10	The distribution of PE_bike_lane_density is the same across categories of CLUSTER.	Independent-Samples Kruskal-Wallis Test	.000	Reject the null hypothesis.
11	The distribution of PE_sharing_points_density is the same across categories of CLUSTER.	Independent-Samples Kruskal-Wallis Test	.000	Reject the null hypothesis.
12	The distribution of PE_road_density is the same across categories of CLUSTER.	Independent-Samples Kruskal-Wallis Test	.000	Reject the null hypothesis.
13	The distribution of PE_interface_density is the same across categories of CLUSTER.	Independent-Samples Kruskal-Wallis Test	.000	Reject the null hypothesis.
14	The distribution of PE_sky_view_factor is the same across categories of CLUSTER.	Independent-Samples Kruskal-Wallis Test	.000	Reject the null hypothesis.
15	The distribution of PE_h_d is the same across categories of CLUSTER.	Independent-Samples Kruskal-Wallis Test	.000	Reject the null hypothesis.
16	The distribution of PE_green_vision is the same across categories of CLUSTER.	Independent-Samples Kruskal-Wallis Test	.000	Reject the null hypothesis.
17	The distribution of PE_urban_furniture_density is the same across categories of CLUSTER.	Independent-Samples Kruskal-Wallis Test	.000	Reject the null hypothesis.
18	The distribution of SE_safety is the same across categories of CLUSTER.	Independent-Samples Kruskal-Wallis Test	.000	Reject the null hypothesis.
19	The distribution of SE_to_attraction is the same across categories of CLUSTER.	Independent-Samples Kruskal-Wallis Test	.000	Reject the null hypothesis.
20	The distribution of SE_to_openspace is the same across categories of CLUSTER.	Independent-Samples Kruskal-Wallis Test	.000	Reject the null hypothesis.

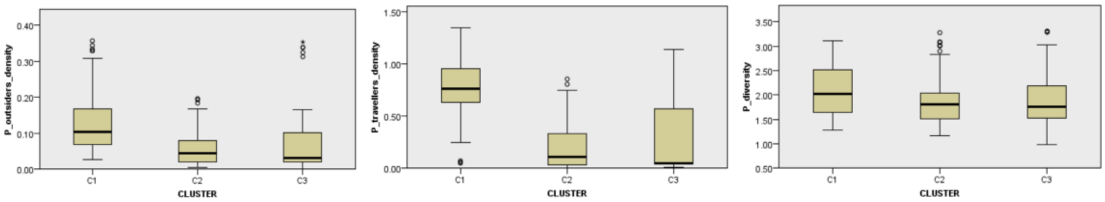
Asymptotic significances are displayed. The significance level is .05.

(1) People

According to the pairwise comparisons, the main difference between three clusters within 300m walking distance lies mainly between Cluster1 (high-mid pattern) and the other two (Fig 6.4-9). As is offered in independent sample test report, streets in Cluster1 are having higher density of outsiders, higher density of travelers and higher diversity of people compared with Cluster2 and Cluster3 (low-low pattern and mid-high pattern respectively).

(a) (b) (c)

Fig 6.4-9 pairwise comparisons between clusters: (a) density of outsiders; (b) density of travelers; (b) diversity of people

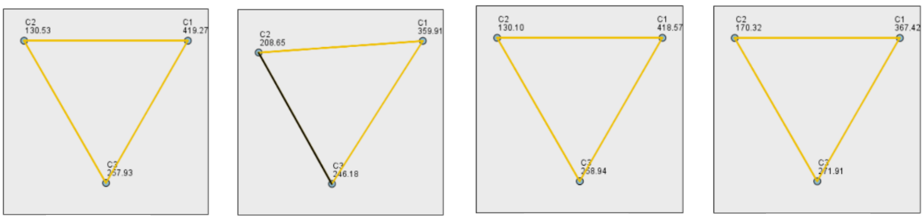


(a) (b) (c)

Fig 6.4-10 independent sample Kruskal Wallis test: (a) density of outsiders; (b) density of travelers; (b) diversity of people

(2) Activities:

Three factors in 'activities' domain are distinguishing streets into three groups (Fig 6.4-11), namely, density of services, percentage of supplied shopping places and density of daily services. For density of services, distribution of data for streets in Cluster1 (high-mid pattern) is generally above the other two clusters, in terms of maximum, minimum and median value. Same kind of law is also found percentage of supplied shopping places and density of daily services. By contrast, data of diversity of services cannot distinguish three clusters but only group out Cluster1 (high-mid mode), which might be caused by the fact that streets with less diversity of services are compensated by streets connected with them. The value of diversity of services in Cluster1 is relatively higher than the other groups but not exceedingly far (Fig 6.4-12).



(a) (b) (c) (d)

Fig 6.4-11 pairwise comparisons between clusters: (a) density of services; (b) diversity of services; (c) percentage of supplied shopping places; (d) density of daily services

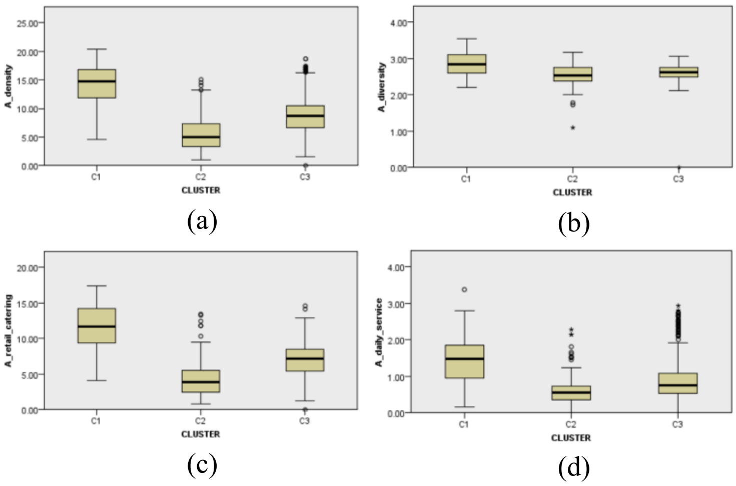


Fig 6.4-12 independent sample Kruskal Wallis test: (a) density of services; (b) diversity of services; (c) percentage of supplied shopping places; (d) density of daily services

(3) Physical environment

Nine factors under ‘physical environment’ domain are considered to influence the functional changing patterns according to hypothesis test and the pairwise comparisons prove the difference manifest (Fig 6.4-13, Fig 6.4-14).

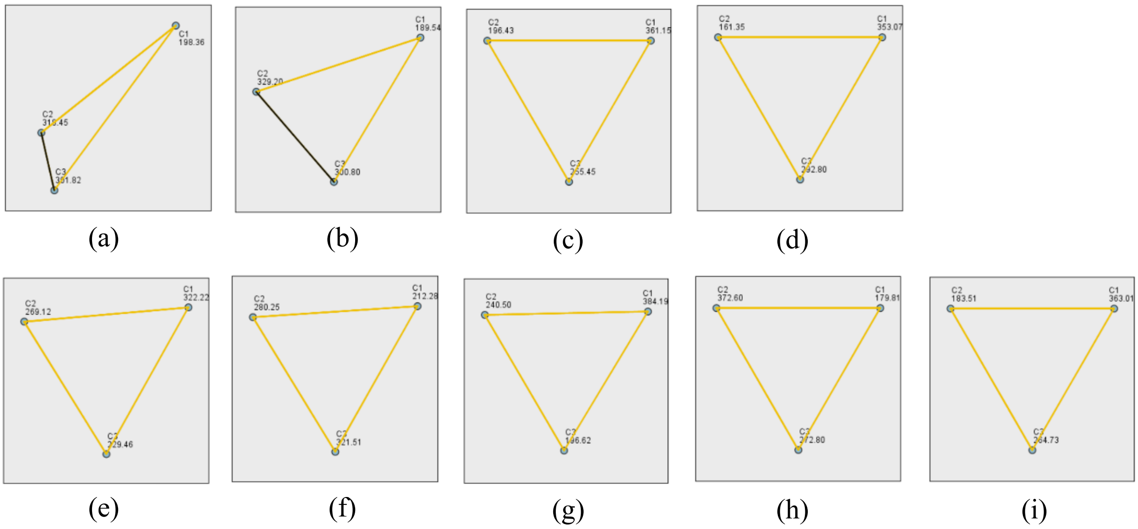


Fig 6.4-13 pairwise comparisons between clusters:

(a) average distance to nearest metro stations; (b) density of bicycle lanes; (c) density of sharing points; (d) network density; (e) interface density; (f) sky view factor; (g) H/D; (h) green vision ratio; (i) street furniture

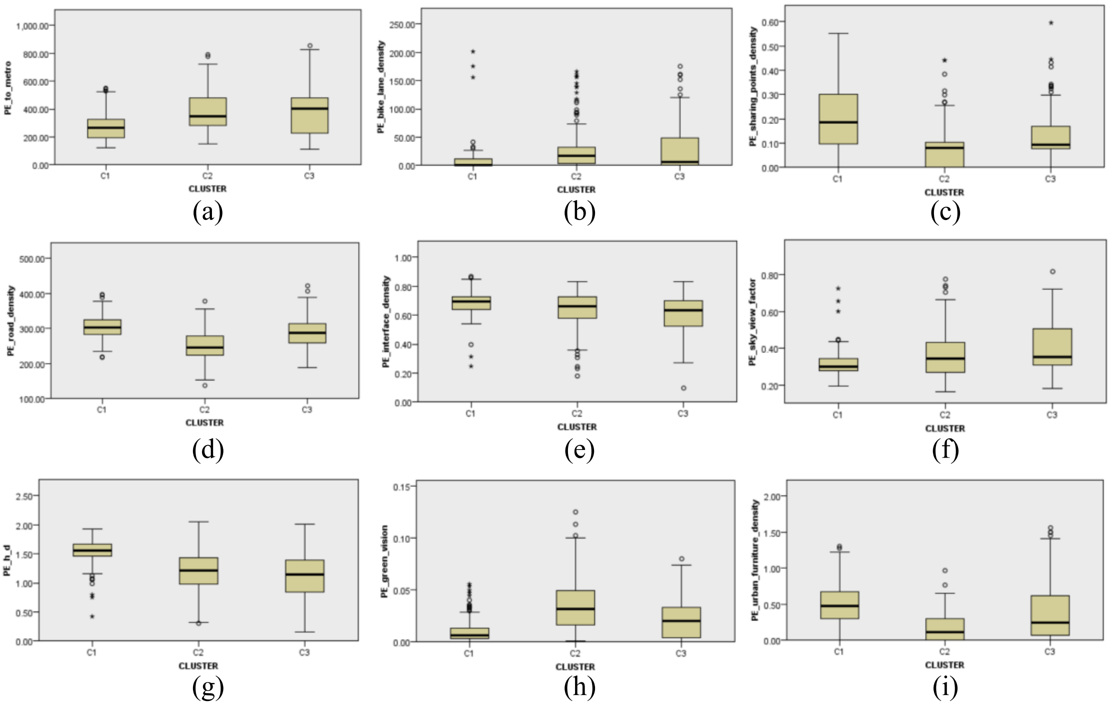


Fig 6.4-14 independent sample Kruskal Wallis test:

(a) average distance to nearest metro stations; (b) density of bicycle lanes; (c) density of sharing points; (d) network density; (e) interface density; (f) sky view factor; (g) H/D; (h) green vision ratio; (i) street furniture

In terms of transportation, average distance to nearest metro stations and density of bicycle lanes are making streets in Cluster1 (high-mid pattern) different from the other two clusters, whereas density of sharing points and network density are distinguishing all three clusters of streets. As is shown in independent sample test, streets in Cluster1 (high-mid pattern) are nearer to the nearest metro stations and has lower density of bicycle lanes. For density of sharing points, data is highest in Cluster1 (high-mid pattern), in the middle for Cluster3 (mid-high pattern) and lowest for Cluster2 (low-low pattern). Similar mode is also found in network density.

In urban forms, streets in Cluster1 are having highest interface density; streets in Cluster2 range in the middle and Cluster3 are having lowest interface density. The mode of SVF is presented oppositely compared with interface density. In spatial cognition, same pattern of data distribution in interface density is found in H/D. Like what is found during the verification for factors influencing functional changing patterns for single streets, streets in low-low mode are having the highest green vision ratio, streets in high-mid mode are the lowest by contrast. And for street furniture factor, high-mid pattern streets are among the highest, with low-low pattern among the least.

(4) Social environment

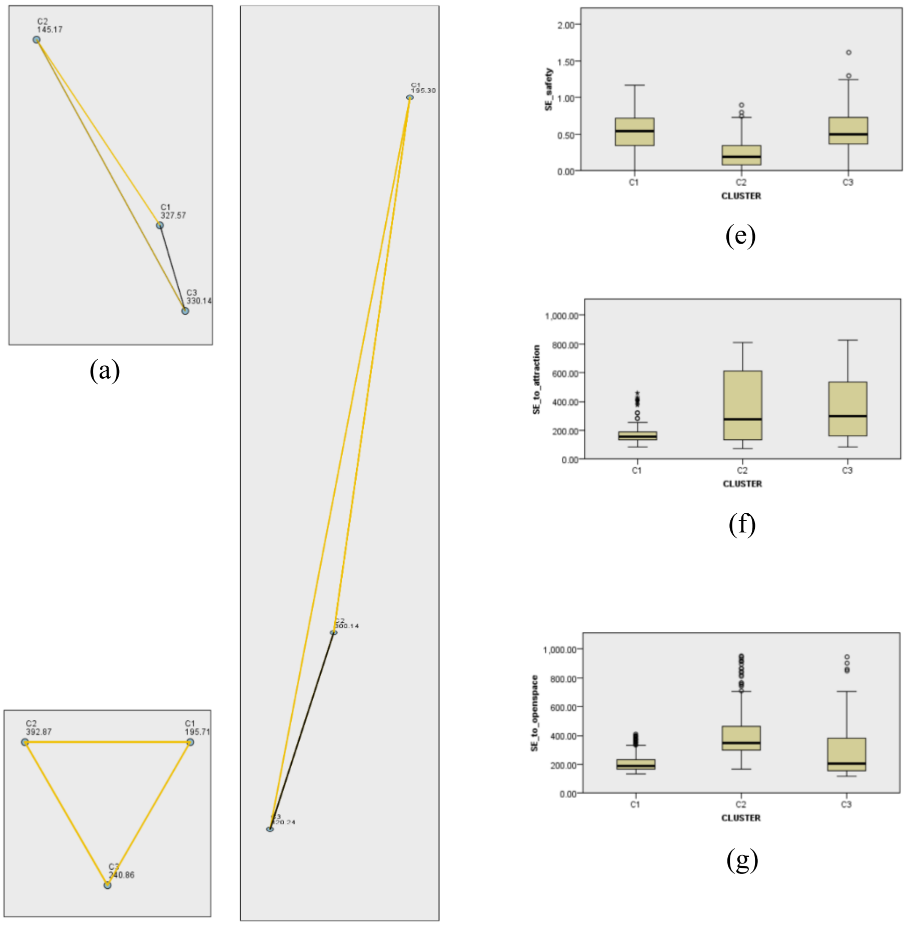


Fig 6.4-15 pairwise comparisons between clusters: (a) density of night services; (b) accessibility to tourist attractions; (c) accessibility to squares/ parks; independent sample Kruskal Wallis test: (d) density of night services; (e) accessibility to tourist attractions; (f) accessibility to squares/ parks

Fig 6.4-15 is presenting comparisons result of factors in 'social environment' domain. For safety, streets in low-low pattern are having relatively lower density of night services. From perspective of landmarks, accessibility to tourist attractions is driving streets in Cluster 1 (high-mid mode) far different from the other groups, whereas for accessibility to squares/ parks, the distribution is similar to what has been found for factors in functional changing patterns within streets.

(5) Summary

To conclude, factors from four defined domains are influencing the functional changing patterns as supposed after the process of verification, among them many are able to separate streets in three clusters. Compared with what has been found for factors in functional changing patterns within streets, it is manifest that 300m walking distance has made difference between groups narrowed by connecting streets with different features together.

2. Functional connectivity within 500m walking distance

According to the hypothesis test summary in Tab 6.4-3, all the proposed factors are influencing the classification of streets. Factors that have rejected the null hypothesis are discussed as follows:

Tab 6.4-3 hypothesis test summary for functional connectivity within 500m walking distance

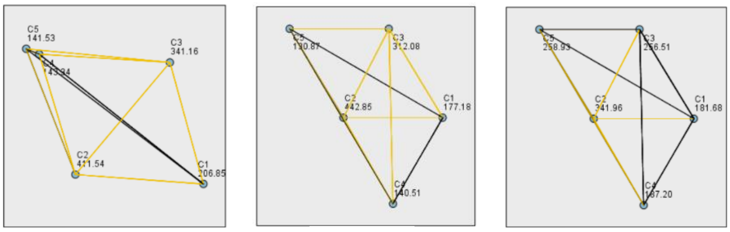
Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of P_outsiders_density is the same across categories of CLUSTER.	Independent-Samples Kruskal-Wallis Test	.000	Reject the null hypothesis.
2	The distribution of P_travellers_density is the same across categories of CLUSTER.	Independent-Samples Kruskal-Wallis Test	.000	Reject the null hypothesis.
3	The distribution of P_diversity is the same across categories of CLUSTER.	Independent-Samples Kruskal-Wallis Test	.000	Reject the null hypothesis.
4	The distribution of A_density is the same across categories of CLUSTER.	Independent-Samples Kruskal-Wallis Test	.000	Reject the null hypothesis.
5	The distribution of A_diversity is the same across categories of CLUSTER.	Independent-Samples Kruskal-Wallis Test	.000	Reject the null hypothesis.
6	The distribution of A_retail_catering is the same across categories of CLUSTER.	Independent-Samples Kruskal-Wallis Test	.000	Reject the null hypothesis.
7	The distribution of A_daily_service is the same across categories of CLUSTER.	Independent-Samples Kruskal-Wallis Test	.000	Reject the null hypothesis.
8	The distribution of PE_bustram_density is the same across categories of CLUSTER.	Independent-Samples Kruskal-Wallis Test	.000	Reject the null hypothesis.
9	The distribution of PE_to_metro is the same across categories of CLUSTER.	Independent-Samples Kruskal-Wallis Test	.000	Reject the null hypothesis.
10	The distribution of PE_bike_lane_density is the same across categories of CLUSTER.	Independent-Samples Kruskal-Wallis Test	.000	Reject the null hypothesis.
11	The distribution of PE_sharing_points_density is the same across categories of CLUSTER.	Independent-Samples Kruskal-Wallis Test	.000	Reject the null hypothesis.
12	The distribution of PE_road_density is the same across categories of CLUSTER.	Independent-Samples Kruskal-Wallis Test	.000	Reject the null hypothesis.
13	The distribution of interface_ is the same across categories of CLUSTER.	Independent-Samples Kruskal-Wallis Test	.000	Reject the null hypothesis.
14	The distribution of PE_sky_view_factor is the same across categories of CLUSTER.	Independent-Samples Kruskal-Wallis Test	.000	Reject the null hypothesis.
15	The distribution of PE_h_d is the same across categories of CLUSTER.	Independent-Samples Kruskal-Wallis Test	.000	Reject the null hypothesis.
16	The distribution of PE_green_vision is the same across categories of CLUSTER.	Independent-Samples Kruskal-Wallis Test	.000	Reject the null hypothesis.
17	The distribution of PE_urban_furniture_density is the same across categories of CLUSTER.	Independent-Samples Kruskal-Wallis Test	.000	Reject the null hypothesis.
18	The distribution of SE_safety is the same across categories of CLUSTER.	Independent-Samples Kruskal-Wallis Test	.000	Reject the null hypothesis.
19	The distribution of SE_to_attraction is the same across categories of CLUSTER.	Independent-Samples Kruskal-Wallis Test	.000	Reject the null hypothesis.
20	The distribution of SE_to_openspace is the same across categories of CLUSTER.	Independent-Samples Kruskal-Wallis Test	.000	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

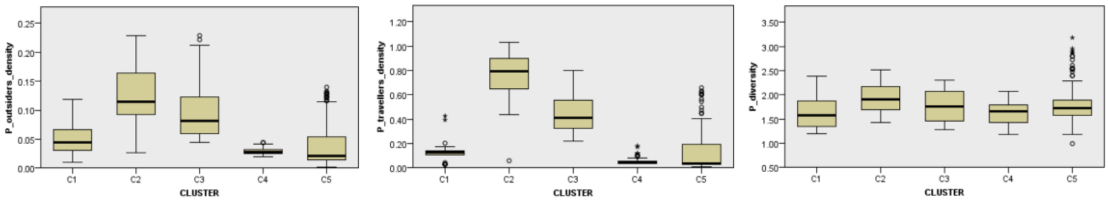
(1) People:

Result of pairwise comparisons between clusters for 'people' domain is shown in Fig 6.4-9. Main difference between the clusters lies in Cluster2 (high-mid pattern) and Cluster3 (mid-low pattern) with the other three clusters. In density of outsiders and travelers, Cluster2 (high-mid pattern) and Cluster3 (mid-low pattern) are special for the significantly higher density than data of other groups. In diversity of people, however, only Cluster2 (high-mid pattern) can be selected out for its higher value than other groups.



(a) (b) (c)

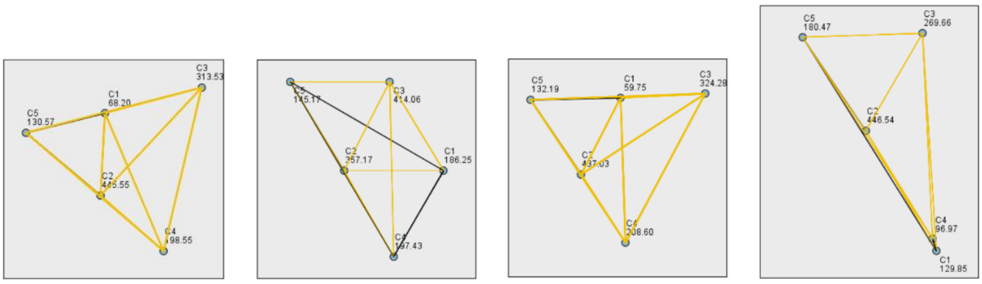
Fig 6.4-16 pairwise comparisons between clusters:
(a) density of outsiders; (b) density of travelers; (b) diversity of people



(a) (b) (c)

Fig 6.4-17 independent sample Kruskal Wallis test:
(a) density of outsiders; (b) density of travelers; (b) diversity of people

(2) Activities



(a) (b) (c) (d)

Fig 6.4-18 pairwise comparisons between clusters: (a) density of services; (b) diversity of services; (c) percentage of supplied shopping places; (d) density of daily services

Unlike factors in 'people' domain, factors in 'activities' domain are influencing the grouping of functional changing patterns to all five clusters, except diversity of services and density of daily services (Fig 6.4-18, Fig 6.4-19). In terms of diversity of services, only Cluster2 and Cluster3 are detected different from other groups for the higher value, with data for Cluster3 (mid-low pattern) on top. Similarly, Cluster2 and Cluster3 are also detected different from other groups for the higher value in density of daily services, with Cluster2 (high-mid pattern) on the top.

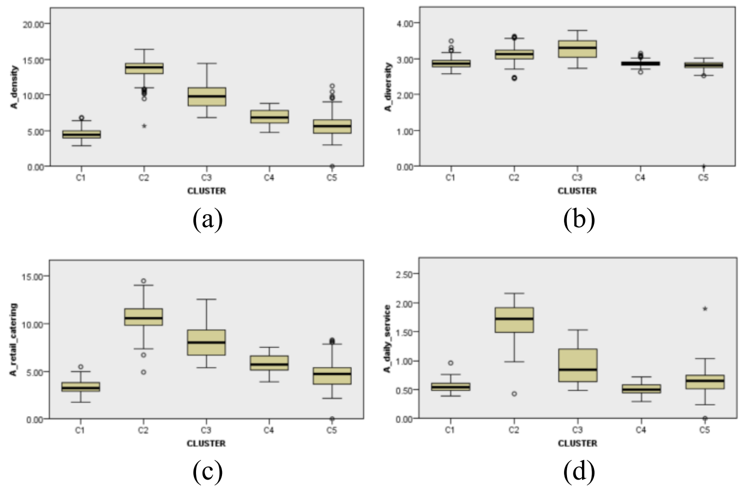


Fig 6.4-19 independent sample Kruskal Wallis test: (a) density of services; (b) diversity of services; (c) percentage of supplied shopping places; (d) density of daily services

Combined with independent sample test, distribution of density of services and percentage of supplied shopping places are similar to each other. Specifically, data for Cluster1 (low-low pattern) and Cluster5 (mid-mid) pattern are at the bottom, with Cluster2 on top, Cluster3 at second place and Cluster4 at third place.

(3) Physical environment

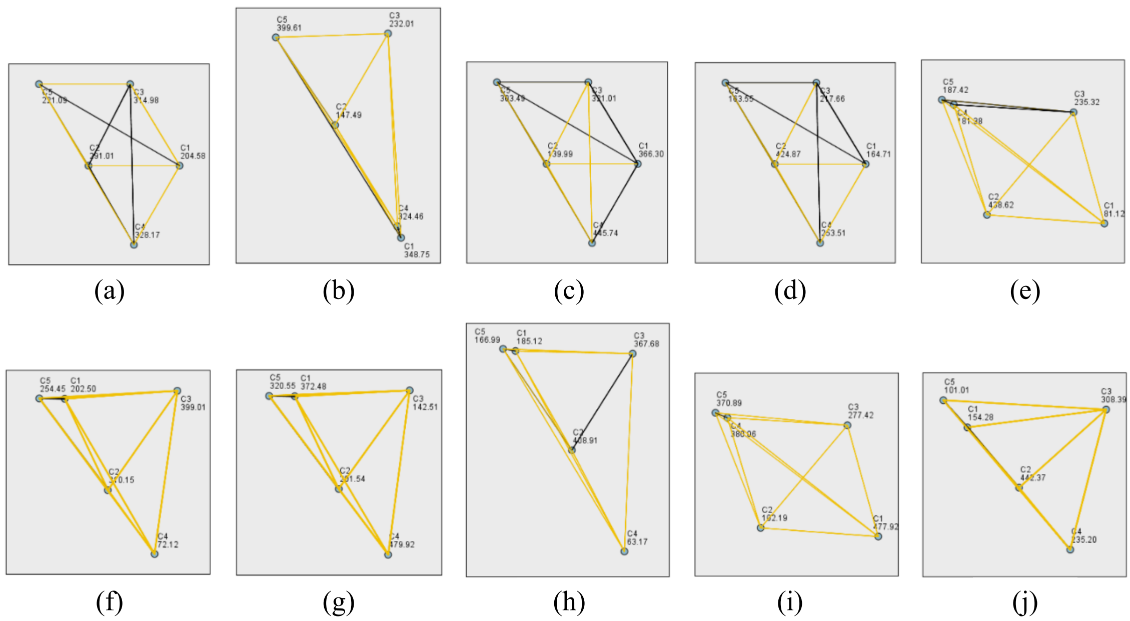


Fig 6.4-20 pairwise comparisons between clusters:

(a) density of bus and tram lines in unit area; (b) average distance to nearest metro stations; (c) density of bicycle lanes; (d) density of sharing points; (e) network density; (f) interface density; (g) sky view factor; (h) H/D; (i) green vision ratio; (j) street furniture

Fig 6.4-20 and Fig 6.4-21 are showing pairwise comparisons between clusters in 'physical environment' domain. According to the map, factors from transportation are not distinguishing out all five clusters but only vary between some of the clusters (Fig 6.4-20/21 (a)(b)(c)(d)(e)). Combining independent sample test, data for Cluster1 (low-low pattern) and Cluster5 (mid-mid pattern) a lower than that for other groups in density of bus and tram lines in unit area. Similar mode is also found in average distance to nearest metro stations as streets in Cluster1 and Cluster5 are further to stations as shown in data. Perspectives of density of bicycle lanes and density of sharing points are quite similar in that they both separate out Cluster2 (high-mid pattern), but the features of distribution are different. For density of bicycle lanes, streets in Cluster2 are the lowest compared with other streets; whereas data of streets in Cluster2 are among the highest for density of sharing points. In terms of network density, Cluster1 (low-low pattern) and Cluster2 (high-mid pattern) are special for ranking at the bottom and the top class respectively.

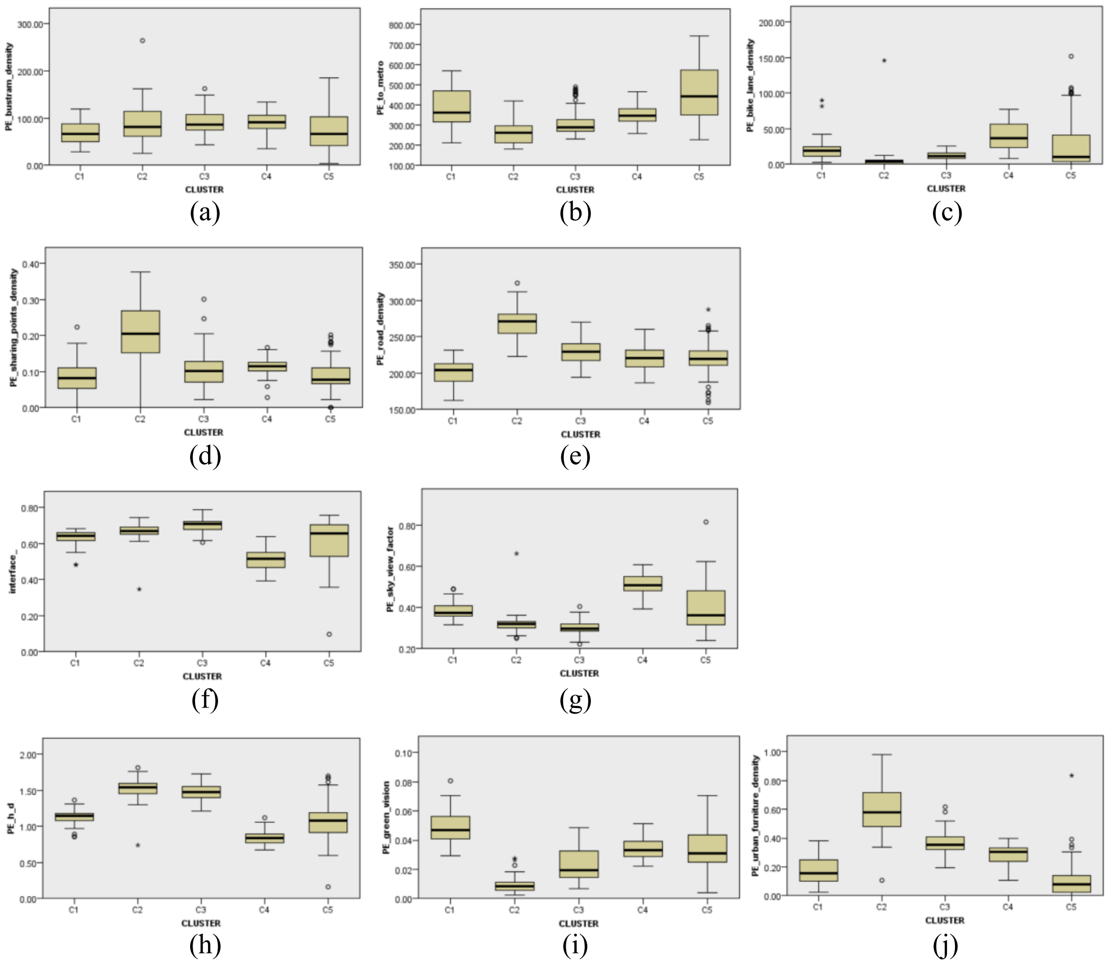


Fig 6.4-21 independent sample Kruskal Wallis test:

(a) density of bus and tram lines in unit area; (b) average distance to nearest metro stations; (c) density of bicycle lanes; (d) density of sharing points; (e) network density; (f) interface density; (g) sky view factor; (h) H/D; (i) green vision ratio; (j) street furniture

Factors of interface density and sky view factor are influencing the clustering of streets explicitly (Fig 6.4-20/21 (f)(g)). Only similarities are found in Cluster1 (low-low pattern) and Cluster5 (mid-mid pattern), as they both rank in the middle in these two factors. In distribution of other clusters, Cluster4 (mid-high pattern) ranks highest and lowest in sky view factor and interface density respectively.

Fig 6.4-20/21 (h)(i) is showing pairwise comparison of factors in spatial cognition. Cluster2 (high-mid pattern) and Cluster3 (mid-low pattern) are similar in H/D, both rank high with narrower streets and higher facades compared with streets from other clusters. Like what has been found in green vision in previous pairwise comparison, the most active ‘high-mid pattern’ is having the lowest ratio of green vision. Cluster2 is also special in street furniture (Fig 6.4-20/21 (j)), with the value exceedingly higher than streets from other groups.

(4) Social environment

As is shown in Fig 6.4-22 and Fig 6.4-23, in terms of density of night services, similarities can be found between Cluster1 (low-low pattern) and Cluster3 (mid-low pattern) for they both rank very low; and between Cluster2 (high-mid pattern) and Cluster4 (mid-high pattern) as they both rank on top among all the clusters. For factors in ‘landmarks’, distance to attractions has made streets in Cluster5 (mid-mid pattern) and Cluster4 (mid-high pattern) special for streets in Cluster5 are exceedingly further to attractions, and streets in Cluster1 second far (about twice the distance compared with streets in Cluster1, Cluster2 and Cluster3). Distance to open spaces has made streets in Cluster1 (high-mid pattern) special for they are further to open spaces compared with other streets.

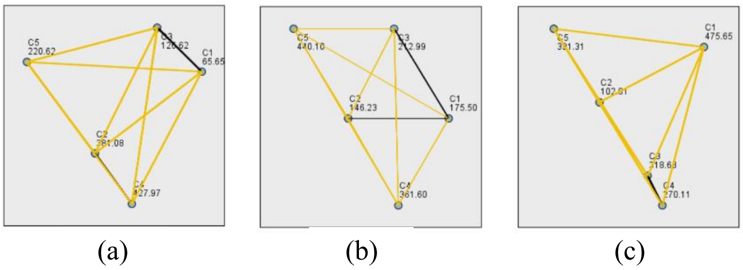


Fig 6.4-22 pairwise comparisons between clusters: (a) density of night services; (b) accessibility to tourist attractions; (c) accessibility to squares/ parks

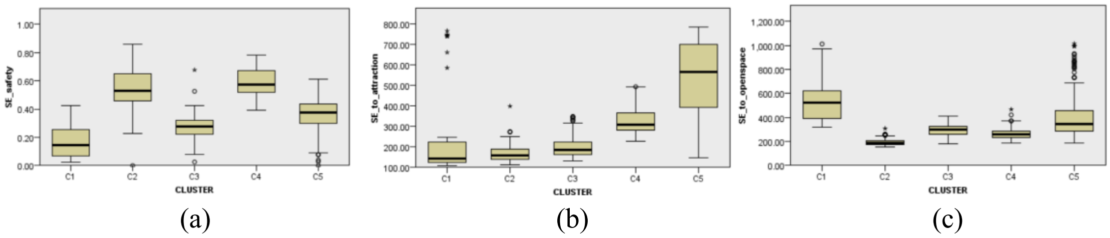


Fig 6.4-23 independent sample Kruskal Wallis test: (a) density of night services; (b) accessibility to tourist attractions; (c) accessibility to squares/ parks

(5) Summary

In verification of factors that influence functional connectivity changing patterns within 500m walking distance, it is found that all the twenty proposed factors are influencing the functional patterns from different extents. If the functional changing patterns are summarized as ‘better connected patterns’ and ‘less connected patterns’, the proposed factors can be divided into three categories.

Firstly, factors that distinguish streets of relatively high functional connectivity from those of low functional connectivity throughout the day. This category includes density of travelers, density of services, density of bus and tram lines, average distance to nearest metro stations, density of sharing points, network density, green vision ratio and accessibility to open spaces. Secondly, factors that characterize streets with very high functional connectivity during the day. Diversity of people, percentage of supplied shopping places, density of daily services, interface density, street furniture and accessibility to tourist attractions. And finally, factors that characterize streets with very high functional connectivity during the evenings. This category is made of density of night services, sky view factor and density of bicycle lanes.

6.5 Summary

This chapter is trying to discover factors that influence functional changing patterns both qualitatively and quantitatively.

Qualitatively, the analysis focuses on the difference between two selected areas. From this sense, this research has laid special stress on historic difference and traffic policy difference between the two areas besides the general differences, which has discovered that: San Babila area has deeper culture deposits compared with China Town- Porta Nuova and is the traditional core of the city, which can explain the high vibrancy functional pattern in San Babila. The traffic policy of Area C has limited motorized traffic in San Babila and Porta Nuova to some extent, which might explain the more accumulation of people in these two areas compared with China Town.

Quantitatively, factors from four domains are proposed for verification, people, activities, physical environment and social environment. As a result, the functional changing patterns of streets are characterized by a combination of factors in these four domains.

Three kinds of factors are defined by how they categorize functional changing patterns of streets. Factors that distinguish streets of relatively high vibrancy changing patterns from those of low vibrancy include density of travelers, density of services, average distance to nearest metro stations, density of sharing points, network density, and accessibility to open spaces. Factors that characterize streets with very high vibrancy functional pattern during the day include diversity of people, percentage of supplied shopping places, density of daily services, interface density, street furniture and accessibility to tourist attractions. And finally, factors that characterize streets with very high functional connectivity during the evenings include night services and sky view factor.

In terms of how these factors influence functional changing patterns, most of the factors are in positive or negative correlation with how vibrancy the changing patterns are. More specifically, functional changing patterns are of high vibrancy feature generally when density of travelers, density of services, density of sharing points, network density are high and nearer to open spaces and metro stations. To get extreme high vibrancy pattern during the day, high diversity of people, high percentage of supplied shopping places, high density of daily services and street furniture as well as easy access to tourist attractions are required. Whereas high density of night services and high value of sky view factor guarantee high vibrancy pattern during the evenings.

Apart from those in positive or negative correlation with vibrancy of the changing patterns, some of the factors are discovered as very special:

First factors are related with transportation (density of bus/tram lines and bicycle lanes), which shows different influence in functional changing patterns when the range of calculated area increase. These factors are examined as a block for accumulation of people on single streets, however, when the walking distance increase to 300m and 500m in functional connectivity, higher density of bus/tram lines and bicycle lanes are help improving vibrancy of the area. Secondly, interface density is a factor influencing functional changing patterns but not in lineal relationship. Streets of high vibrancy functional changing patterns rank in the middle in this factor which means very high or low interface density are neither helping accumulation of people. Thirdly, green vision ratio is a factor that act differently from people’s cognition, that is, streets with high green vision ratio are among the least visited.

Chapter 7 Conclusions

7.1 Conclusion of the Research

This research is trying to study the functional changing patterns of two selected streets from intermediate or micro perspective, which is different from the scale of traditional researches using big data. The functional changing patterns are summarized through K-means clustering in two different lineal processes which are 'function of streets' from limited sense and in general terms respectively.

From limited sense, 'function of street' is understood as visible functions that provide products or services. Functional changing of streets in this sense can be summarized in six patterns: (1) '7-24' vitality; (2) activated only during peak hours; (3) high vibrancy during the day but not active during the night, and distinguished by compound functions of daily services, local shops, shopping places and culture recreations during peak hours. (4) distinctive for open spaces and culture recreations during peak hours and activated by additional functions of caterings and local shops during other time of the day; (5) high vibrancy during the day but with only several streets staying active during the night, and distinguished by compound functions including groceries, caterings and local shops during peak hours; (6) staying relatively inactive during the whole day.

In general terms, 'function of street' is defined as the functional connectivity of streets in integrating 'functions' defined in limited sense, which are invisible in physical space. Three dimensions of functional connectivity are discussed, within streets, 300m walking distance and 500m walking distance. And the functional changing patterns of streets are summarized in 'day-night' value format. Value of functional connectivity is described by 'high', 'mid' and 'low' according to how they rank compared with other clustering centers.

For functional connectivity within single streets, three functional changing patterns are concluded: high – high, mid – mid and low – low; within 300m walking distance, three functional changing patterns are concluded: high – mid, low – low and mid – high; within 500m walking distance, five functional changing patterns are concluded: low – low, high – mid, mid – low, mid – high and mid – mid.

Furthermore, factors that influence functional changing patterns of streets are analyzed qualitatively and quantitatively. It is found that the functional changing patterns of streets are result of combination of many factors.

High density of travelers, density of services, density of sharing points, network density and easy accessibility to open spaces and metro stations are usually connected with functional changing patterns in high vibrancy feature. High diversity of people, high percentage of supplied shopping places, high density of daily services and street furniture as well as easy access to tourist attractions are required to get extreme high vibrancy pattern during the day. Whereas high density of night services and high value of sky view factor lead to high vibrancy pattern during the evenings. The influence mechanism of transportation, interface density and green vision are found especially different from what has been found in existed researches. Maintaining reasonable interface density and transportation intensity can also help with attraction of people.

7.2 Limitation of the Research

Limitation of the research comes from mainly three aspects:

1. Limitation of sources of data

This thesis has used combination of Google popular times data and Foursquare data to conduct dynamic research of the city. Google popular times gives how total visitors to functional points are allocated in different time periods whereas Foursquare data provide accumulative number of visitors to functional points. These two sources of data are actually of different temporal span as Google Popular times is detected every day for every hour whereas Foursquare is sum up of all historic check-ins. These two sources of data are not temporally matched from strict sense.

Additionally, it is undeniable that big data taken from social media has always been faced with problem related with sample coverage. Only people who are using the media will be taken into consideration, which is inevitably losing data from non-users. From this sense, data based on can be better replacement, like Google popular times and mobile signaling data.

Apart from limitation of sources of data linked with quality, the accessibility of data has affected researches using big data more. Foursquare data is showing trend of less users in recent years, which means the quality of data might be in low creditability. This research has tried to combine other sources of data to better get the check-ins on each function points, but popular sources like Twitter has stopped offering API for personal use since December 2018. Better quality sources of data based on mobile phone are also even relatively harder to access compared with social media data. For example, Google popular times has not opened API yet for people to access; whereas accessing mobile phone signaling data requires higher criteria which is almost impossible for personal researchers.

2. Variation between data and reality

This research is trying to use big data to study the functional changing patterns of streets from intermediate or micro perspective like traditional observation methods. To some extent, this has been realized by getting an explicit view on activated functions for each time periods. However, the problem is in reality, streets, as shared space, is taking more functions besides what has been defined in ‘function of streets’. These excluded functional points may even not available on map and can be only observed at site. Typical examples include street arts, small markets and special activities. Although unavailable from map, they are providing serves, products and attracting people all the time.

3. Limitation in explanation of the verification result

This research tries to examine if the 20 proposed factors are influencing functional changing patterns, with most of them being verified as working. However, the result might not be universal but limited in research areas because of finite number of streets being analyzed. It is still necessary to find out if the difference between functional changing patterns is caused by the proposed factors or just coincidence.

7.3 Application of the Research

The method used in this research and the tentative conclusion drawn from the analysis have great value in application:

Firstly, this research helps to quantify the spatial and temporal changes of street functions and functional linkages, expanding the scope of traditional methods to block and city scales, saving manpower and material resources when starting the site analysis before design.

Secondly, as functional changing patterns in high vibrancy are usually the target of urban design or urban renovation, improvement in density of services, density of sharing points, network density and H/D as well as allocation of open spaces may be applied. Besides, maintaining reasonable interface density and transportation intensity can also help with attraction of people. What should not be forgotten is that there are still some factors not defined by planners like distribution of people.

Finally, besides clustering of the functional changing patterns, this research is also providing a way to detect dynamic features of people's behavior in space. Based on this, data-based design like planning of city events and exhibitions can be better conducted.

7.4 Research Prospects

This research can be further developed as follows:

The methods used in this research has been from intermediate or micro perspective, applying to two streets districts in Milan because of technical limitation. In later on research, this method can be applied to a bigger scale like city level, to understand functional changing patterns of the streets in the city, or comparison of functional changing patterns of the streets between different cities.

Temporally, this research has collected data of March 4th-March 10th and April 1st-April 7th, avoiding festivals and feast days to exclude unnecessary influences. Comparisons of functional changing patterns happen during eight time periods defined during the day and between weekdays and weekend. There is possibility that seasonal difference between functional changing patterns being studied. Additionally, difference between time periods of long holidays as well as big events and time periods without can be further studied using the methods proposed in this research to better understand the effects of special events on spatial usage.

Although some of the data sources have been blocked, it is still expected that in the future, new data source like Google popular times can offer chance to collect data with higher efficiency. Besides, more effective combination of data and analysis can also help further research. Application of semantic recognition and picture recognition technology can provide more precise analysis on factors that influence functional changing patterns of streets. Furthermore, apart from how the function of streets change, who are using the space can also be a research branch.

Some of the conclusions like influence mechanism of transportation, interface density and green vision on functional changing patterns remain to be examined if they still working in bigger scale. From this sense, variable-controlling approach can be further applied during future development of the research, combining monitor of functional changing patterns in longer time interval to get better results.

Thanks

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Annexes

A. Python code

A.1 Python code for acquiring check-in information:

In this part, the codes are composed of two parts, first is acquiring Foursquare ids of POIs in category defined according to official file given by Foursquare; second is tracing details of POIs including check-ins, comments, likes, etc. through ids.

Step 1: acquiring ids of POIs

```
# import necessary package to process data in JSON format
import simplejson, json, time
from decimal import Decimal

import foursquare

# write into a text file
#import importlib,sys
#importlib.reload(sys)
import sys
import time
reload(sys)
sys.setdefaultencoding('utf-8')

#construct client object
client=foursquare.Foursquare(client_id='0XACUWQ5YMYIPB03IAVHCHUBFIALI
402MFBMYUMRVSSZR2DS',
client_secret='XUTR44N1GAFSE1ZCUAHLWY5WZZ1IK0BMNECY3OCJ2M3FD
IUE')

s=set('')
sw=45.455

while sw<=45.495:
    s.add(sw)
    sw=sw+0.0055

sw_sorted=sorted(s)

list1=[] #define a list for ID

for sw_s in sw_sorted:
    ne_s=sw_s+0.0055
```

```
    sw_h=9.158
    ne_h=sw_h+0.008

    while ne_h<=9.213:
        query_result=client.venues.search(params={
            'limit':50,
            'intent':'browse',
            'sw':str(sw_s)+','+str(sw_h),
            'ne':str(ne_s)+','+str(ne_h),
            'categoryID':'4d4b7105d754a06373d81259'
            })

        if any(query_result['venues']):
            time.sleep(1)

            for x in xrange(len(query_result['venues'])):
                a=query_result['venues'][x]
                # a is a dict
                list1.append(str(a['id']))

        ne_h=ne_h+0.008
        sw_h=sw_h+0.008

filename="for_id_Event"
output=open(filename,'a')
sys.stdout=output
print list1
```

Step 1: acquiring details of POIs

```
# import necessary package to process data in JSON format
import simplejson, json, time
from decimal import Decimal

import foursquare

# write into a text file
#import importlib,sys
#importlib.reload(sys)
import sys
import time
reload(sys)
sys.setdefaultencoding('utf-8')
```

```
#construct client object
client=foursquare.Foursquare(client_id='0XACUWQ5YMYIPB03IAVHCHUBFIALI
402MFBMYUMRVSSZR2DS',
client_secret='XUTR44N1GAFSE1ZCUAHLWY5WZZ1IK0BMNECY3OCJ2M3FD
IUE')

a=open('for_id_Event','r').read()
a=a.replace("[","")
a=a.replace("]","")
a=a.replace("'","")
a=a.replace(",","")
b=a.split()

filename="for_details_Event.json"
output=open(filename,'a')
sys.stdout=output

details=[] #define a list for details
list_final=[]
cate_list=[]

for i in xrange(len(b)):
    details.append(client.venues(b[i]))
    time.sleep(1)
    dict_details=details[i]['venue']
    print simplejson.dumps(dict_details, ensure_ascii=False, encoding='utf8',
indent=4)
```

A.2 Python code for SSE:

```
import pandas as pd
from sklearn.cluster import KMeans
import matplotlib.pyplot as plt

df_features = pd.read_csv(r'W4.csv', encoding = 'gbk') #read file

SSE = [] #save sum of squared errors of each run
for k in range(1,9):
    estimator = KMeans(n_clusters=k) #construct cluster
    estimator.fit(df_features[['F1','F2','F3','F4','F5','F6','F7','F8','F9','F10']])
    SSE.append(estimator.inertia_)

x=range(1,9)
plt.xlabel('k')
```

```
plt.ylabel('SSE')
plt.plot(x,SSE,'o-')
plt.show()
```

A.3 Python code for silhouette coefficient

```
import pandas as pd
from sklearn.cluster import KMeans
from sklearn.metrics import silhouette_score
import matplotlib.pyplot as plt

df_features = pd.read_csv(r'W8.csv', encoding = 'gbk')

scores=[]
for k   in range(2,13):
    estimator = KMeans(n_clusters=k) #construct cluster
    estimator.fit(df_features[['F1','F2','F3','F4','F5','F6','F7','F8','F9','F10']])
    scores.append(silhouette_score(df_features[['F1','F2','F3','F4','F5','F6','F7','F8','F9
','F10']],estimator.labels_, metric='euclidean'))

x=range(2,13)
plt.xlabel('number of clusters-k')
plt.ylabel('silhouette coefficient')
plt.plot(x,scores,'o-')
plt.show()

plt.plot(x,SSE,'o-')
plt.show()
```

B. SPSS reports

B.1 Sample report of K-means Clustering for functional changing patterns of streets from limited sense

Quick Cluster-week-13-15h

Initial Cluster Centers

	Cluster							
	1	2	3	4	5	6	7	8
F1	1.00000	.00000	.33333	.00000	.16667	.16667	.00000	.16667
F2	.81818	.45455	.18182	.00000	.27273	.81818	.27273	.27273
F3	.00000	.66667	.00000	.00000	1.00000	.66667	.00000	.00000
F4	.50000	.50000	.12500	.00000	.00000	.12500	.25000	.12500
F5	.50000	.00000	.00000	.00000	.50000	.00000	1.00000	.50000
F6	.25000	.50000	.00000	.25000	.00000	.50000	.00000	.00000
F7	.75000	.00000	.00000	.00000	.00000	1.00000	.25000	.00000
F8	.00000	.50000	.00000	.00000	.00000	.00000	.00000	1.00000
F9	.21053	.31579	.31579	.00000	.05263	.15789	.00000	.10526
F10	.00000	.00000	.00000	1.00000	.00000	.00000	.00000	.00000

Iteration History[a]

Iteration	Change in Cluster Centers							
	1	2	3	4	5	6	7	8
1	.463	.519	.361	.526	.519	.421	.538	.438
2	.000	.353	.054	.119	.096	.197	.062	.241
3	.000	.112	.024	.028	.078	.181	.000	.169
4	.000	.059	.009	.012	.053	.093	.025	.030
5	.000	.033	.006	.000	.042	.064	.000	.000
6	.000	.013	.004	.000	.000	.069	.036	.000
7	.000	.015	.002	.015	.000	.051	.000	.000
8	.000	.020	.003	.000	.000	.050	.020	.000
9	.000	.025	.009	.000	.040	.078	.026	.000
10	.000	.022	.006	.014	.000	.064	.000	.000
11	.000	.008	.002	.000	.057	.044	.000	.000
12	.000	.000	.006	.000	.000	.034	.000	.000
13	.000	.000	.000	.000	.000	.000	.000	.000

a. Convergence achieved due to no or small change in cluster centers. The maximum absolute coordinate change for any center is .000. The current iteration is 13. The minimum distance between initial centers is 1.114.

Final Cluster Centers

	Cluster							
	1	2	3	4	5	6	7	8
F1	.83333	.25321	.04219	.10985	.07018	.20068	.06667	.09896
F2	.68182	.29196	.08890	.15702	.22488	.59555	.22424	.13352
F3	.16667	.05769	.06962	.06061	.75439	.13605	.04444	.03125
F4	.56250	.17308	.05973	.04545	.07237	.08163	.10000	.07031
F5	.50000	.00962	.00000	.00000	.05263	.04082	.53333	.10938
F6	.25000	.59135	.05301	.15909	.14474	.16327	.07500	.07813
F7	.50000	.03846	.03165	.05682	.13158	.13776	.06667	.00781
F8	.25000	.01923	.00000	.00000	.10526	.00000	.01667	.53125
F9	.31579	.17206	.07662	.16986	.07202	.08915	.04737	.04770
F10	.00000	.02885	.00000	.51136	.02632	.04082	.10000	.03125

ANOVA

	Cluster		Error			
	Mean Square	df	Mean Square	df	F	Sig.
F1	.551	7	.017	536	31.813	.000
F2	1.775	7	.018	536	96.632	.000
F3	1.270	7	.020	536	63.535	.000
F4	.158	7	.017	536	9.590	.000
F5	1.214	7	.006	536	188.860	.000
F6	1.892	7	.019	536	97.766	.000
F7	.156	7	.014	536	11.395	.000
F8	1.226	7	.004	536	312.142	.000
F9	.129	7	.018	536	7.126	.000
F10	1.466	7	.007	536	208.212	.000

The F tests should be used only for descriptive purposes because the clusters have been chosen to maximize the differences among cases in different clusters. The observed significance levels are not corrected for this and thus cannot be interpreted as tests of the hypothesis that the cluster means are equal.

Number of Cases in each Cluster

Cluster	1	2.000
	2	52.000

	3	316.000
	4	44.000
	5	19.000
	6	49.000
	7	30.000
	8	32.000
Valid		544.000
Missing		.000

B.2 Sample report of K-means Clustering for functional changing patterns of streets in general terms

Quick Cluster

Initial Cluster Centers

	Cluster		
	1	2	3
N1	.401578	.156947	.708876
N2	.153407	.060895	.410768
N3	.103130	.032801	.999184
N4	.549678	.000000	.832801
N5	.577829	.000000	.921959
N6	.543653	.000000	.924792
N7	.589247	.000000	.886075
N8	.585174	.105516	.903549

Iteration History[a]

	Change in Cluster Centers		
Iteration	1	2	3
1	.466	.583	.488
2	.029	.143	.057
3	.025	.031	.022
4	.021	.010	.015
5	.016	.019	.007

6	.023	.010	.013
7	.022	.022	.008
8	.016	.008	.009
9	.026	.004	.018
10	.033	.013	.021
11	.032	.021	.015
12	.041	.023	.019
13	.057	.029	.031
14	.063	.027	.037
15	.024	.008	.019
16	.032	.018	.018
17	.035	.019	.020
18	.029	.018	.014
19	.031	.015	.015
20	.011	.003	.008
21	.005	.004	.007
22	.006	.008	.003
23	.010	.006	.006
24	.000	.003	.003
25	.000	.000	.000

a. Convergence achieved due to no or small change in cluster centers. The maximum absolute coordinate change for any center is .000. The current iteration is 25. The minimum distance between initial centers is 1.223.

Final Cluster Centers

	Cluster		
	1	2	3
N1	.181869	.104169	.542824
N2	.038054	.044203	.293260
N3	.742019	.353870	.691394
N4	.789572	.443353	.622358
N5	.811613	.455371	.674475
N6	.800539	.428948	.626809
N7	.793939	.429524	.670677
N8	.578610	.314511	.727849

ANOVA

	Cluster	Error	F	Sig.

	Mean Square	df	Mean Square	df		
N1	10.205	2	.024	541	432.822	.000
N2	3.991	2	.027	541	145.589	.000
N3	7.697	2	.024	541	318.365	.000
N4	5.206	2	.011	541	475.588	.000
N5	5.583	2	.011	541	495.981	.000
N6	5.998	2	.013	541	459.001	.000
N7	5.934	2	.012	541	513.632	.000
N8	7.804	2	.024	541	330.201	.000

The F tests should be used only for descriptive purposes because the clusters have been chosen to maximize the differences among cases in different clusters. The observed significance levels are not corrected for this and thus cannot be interpreted as tests of the hypothesis that the cluster means are equal.

Number of Cases in each Cluster

Cluster	1	181.000
	2	167.000
	3	196.000
Valid		544.000
Missing		.000

B.3 Sample report of Non-parametric Test

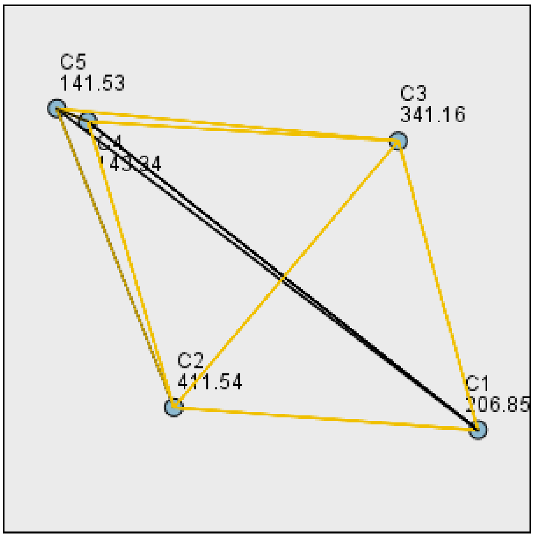
Nonparametric Tests

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of P_outsiders_density is the same across categories of CLUSTER.	Independent-Samples Kruskal-Wallis Test	.000	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Pairwise Comparisons of CLUSTER

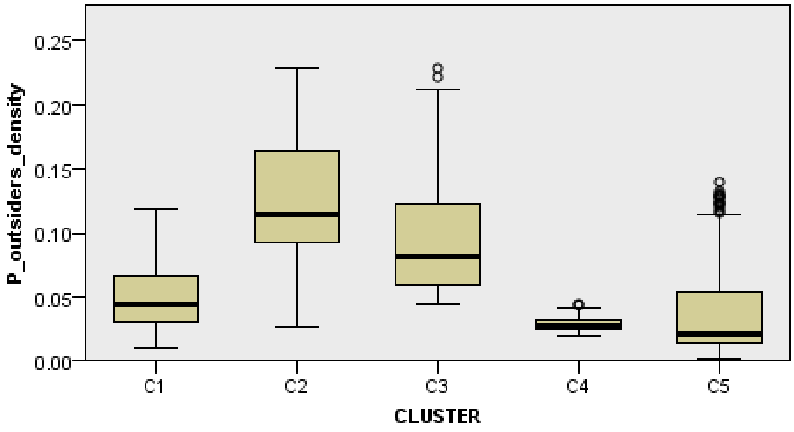


Each node shows the sample average rank of CLUSTER.

Sample1-Sample2	Test Statistic	Std. Error	Std. Test Statistic	Sig.	Adj.Sig.
C5-C4	1.804	23.099	.078	.938	1.000
C5-C1	65.316	27.769	2.352	.019	.187
C5-C3	199.627	20.472	9.751	.000	.000
C5-C2	270.001	16.941	15.937	.000	.000
C4-C1	63.512	31.587	2.011	.044	.444
C4-C3	197.823	25.412	7.785	.000	.000
C4-C2	268.197	22.664	11.834	.000	.000
C1-C3	-134.311	29.721	-4.519	.000	.000
C1-C2	-204.685	27.408	-7.468	.000	.000
C3-C2	70.374	19.980	3.522	.000	.004

Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same.
Asymptotic significances (2-sided tests) are displayed. The significance level is .05.

Independent-Samples Kruskal-Wallis Test



Total N	544
Test Statistic	325.130
Degrees of Freedom	4
Asymptotic Sig. (2-sided test)	.000

1. The test statistic is adjusted for ties.