Analyzing the Spatial Patterns of the Elderly's Daily Activities

Using Data from Smartphones and Wearable Devices

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Introduction

The living environment is an important resource for Chinese cities to response the challenge of aging population. In an ideal living environment, elderlies can obtain necessary support when their physical functions gradually decline due to aging. Their service needs arising out of weakened self-care ability and sharp decline in family care resources can be satisfied in a timely manner. The loneliness that may be caused by transformation of social roles can be appropriately eased. However, the traditional planning process usually specifically targets the service objects without age and gender differences. They only think about urban roads and traffic flow when thinking about daily travels and functional land and public facilities when thinking about services. When group differences and individual needs are ignored, the functions of the built environment and service performance can't be guaranteed. From another point of view, an external environment without sufficient barrier-free facilities as well as a comfortable physical environment may reduce the willingness of the elderly to go out for activities. Thus, it will result in reduction of healthy behaviors. The possible shortage of public service facilities or poor accessibility may cause inconvenience to the elderly and lead to a lower life quality.

In order to further implement the Healthy and Active Aging Strategy (WHO, 2007), an increasing number of countries and cities attach great attention to the elderly-oriented improvement of the built environment and explore spatial strategies to improve the community and home to a more elderly-oriented environment through planning and design. Planning designers and community service providers should re-examine the existing living environment from the standpoint of specific groups and think about the rigid practices of traditional planning, such as allocating resources based on administrative divisions, static demographic statistics, and planning indicators. They should also explore innovative planning methods and tools. Therefore, our study attempts to explore a demand-responsive spatial intervention countermeasure through new types of data and technical routes from a professional perspective of urban planning and public services.

Study base: bird's-eye view of TJ New Village

1. Opportunities and Challenges

1.1 Technology progress brings new possibilities

The characteristics of the built environment and the configuration of public service facilities will directly and indirectly affect the life quality and health of the elderly. Understanding the elderly's utilization of the built environment, the preference of facilities, as well as the characteristics and patterns of their daily activities is an important prerequisite to improve the elderly friendliness at the community level. However, traditional travel surveys, questionnaire interviews, and field observations were unable to provide a sufficient basis, nor can they reflect the spatial and temporal changes of some specific environmental factors. Therefore, it's of an urgent need to promote innovations in data collecting and study methods.

The mobile positioning technology first appeared in the United States. Since the Federal Communications Commission (FCC) of the United States required mobile phone operators to provide location services for users in 1996, The mobile positioning technology has developed rapidly, accumulating massive travel data of mobile phone users. According to different types of positioning technology, the location trajectory data of mobile phones is divided into mobile signaling data and GPS trajectory data. The signaling data has been used in urban planning studies to analyze the wide-area spatial characteristics, such as people's travel behavior and employment distribution. The GPS data has attracted high attention due to its advantages in precisely revealing the characteristics of individual behavior, providing real-time mobile information, stimulating travel route, and predicting Points of Interest (POIs). However, GPS data has not been fully used in planning, research, and application at this stage because of the unsolved challenges in big-data collection, analysis, and practical application.

As indicated by the urban planning development, the planning and countermeasures made at urban and community levels are more inclined to transforming from simple space interference to combination of social, economic and environmental governance, as well as from the traditional standardized configuration planning to user-oriented responsive planning. The relationship between planning and design and its service objects is becoming much closer. Through identifying problems in the built environment based on the characteristics of residents' spatial behaviors and summarizing the rules and characteristics of residents' spatial utilizations, it is helpful to grasp the demand structure of specific residents in a refined way. It also provides scientific basis for planning, decision-making, and environmental design. This is not only an important shift in traditional planning thinking, but also a technical challenge for improving people's quality of life through planning and design.

This project takes the elderly as the study object for two reasons: firstly, in the face of severe challenges brought by the aging population in China, we should urgently take corresponding measures to improve the senior service during community construction; secondly, as elderly's daily activity patterns are relatively simple, the built environment in a community has a more significant support and restraint effect on their daily activities. Thus, elderly people are the ideal population to carry out spatial behavior study at the community level.

Speaking of the goal of improving people's life quality through science and technology, young people are often considered to be the biggest beneficiaries of scientific and technological advances because of their great adaptation to changes. However, for the elderly who are increasingly disconnected from society and whose physical and mental health is declining, involving new technologies into their daily lives is much more important. Unlike young people, the aging population is less resilient and more difficult to obtain substitutes. In view of this, the needs of adopting innovations to solve the problems that cannot be solved by traditional resource allocation and service supply are increasing. Examples include: To optimize the allocation of space and facility resources by acknowledging the daily activities and behaviors of elderly residents in the community, to adjust the supply structure of public services by understanding the elderly residents' preference for the use of public service facilities, to recognize the direction of elderly-oriented rehabilitation by evaluating the use of specific built environments, to carry out activity simulation and prediction through understanding activity patterns and exploring mechanisms. Through above research, we will be able to develop forward-looking and smart solutions for elderly-oriented facilities in the community level.

1.2 Purpose and Significance of the Study

The built environment in urban-rural areas in China have relatively weak foundation for building elderly-oriented facilities. The planning practices, corresponding policies, and technological innovations fall behind the rapidly growing demand for elderly services. Firstly, the practices carried out in various places mainly focus on addressing the shortage of elderly care institutions. There is also a lack of attention to the construction of public living environments which are suitable for the elderly. Secondly, the elderly is a group that has great differences within, such as the condition of the living environment. Since these differences are hard to discover through general statistical concepts, it is difficult to achieve the policies for refined spatial governance that is based on specific conditions by using traditional planning and decision-making. To achieve the development goals of improving residents' quality of life and to promote healthy and active ageing, the planning and design should pay more attention to spatiotemporal behavior of the elderly residents. We should also explore the elderly's travel pattern and decision-making mechanism. Through the above information, we will then be able to provide real-time, customized, personalized information services as well as the decision-making support in the process of allocating environment, facilities, and service elements.

To achieve the goals listed above, this study used smart devices to monitor the behaviors of the elderly in their daily lives under the built environments of specific communities for 102 days. As a result, we delivered phased research results through data mining, information reading, and translation. Results are as listed:

(1) Discover scientific knowledge.

By collecting the trajectory and health data of the elderly residents, the characteristics and patterns of the spatiotemporal behavior of the elderly under specific built environments are summarized. The theoretical and analytical models are explored to be constructed, so as to better reveal the influence mechanisms of built environments on the lifestyle of the elderly.

(2) Propose intervention countermeasures.

The simulation evaluation of urban planning corresponding to residents' behaviors is strengthened. The human-based, dynamic, and refined time and space policies are adjusted to reduce the restriction on residents' spatio-temporal behavior, to improve the accessibility of time and space, and to encourage healthy behaviors. The planning intervention ideas are put forward to encourage the elderly's health behaviors and improve the level of elderly-oriented environment based on the characteristics of specific built environments.

(3) Innovation, discovery and summary of study methods.

At present, there is no developed transcendental theoretical knowledge and analytical methods to study the environmental factors, residents' behaviors, the effects of environmental interventions on residents' health, and other aspects. Therefore, one of the important purposes of this study is to explore and summarize applicable study methods and technical tools.

2. Study condition and design[1]

The research requires equipment (including hardware and software) and research objects (including sample communities and the elderly). After cleaning and classifying the data collected, we carried out the analysis according to the research topic. This report introduces the preliminary findings through visualizing the spatial behaviors, behavioral space, and health data which are collected from the elderly residents in the community (Figure 2-1).

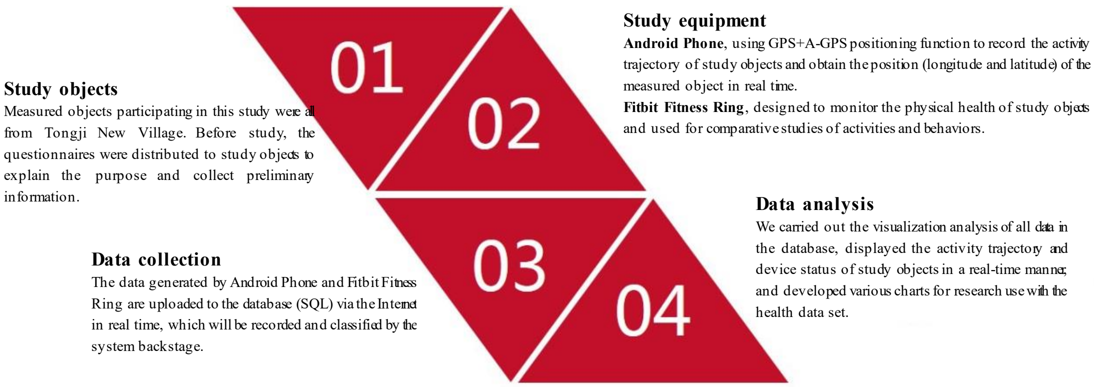


Figure 2-1 Study Steps

2.1 Study equipment and objects

(1) Study equipment

■Android Phone

Under the premise of backstage data, this project chose Redmi Smartphone which uses the Android system. We use its GPS+A-GPS location function and specially developed software to record the activity trajectory of study objects. These functions can also obtain the longitude and latitude coordinates of measured objects in real time (Figure 2-2).

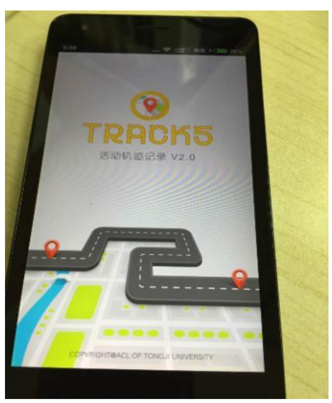


Figure 2-2 Redmi Smartphone

Figure 2-3 Fitbit

[1] This study has passed the ethics approval of Tongji University (2015yxy112).

■Fitbit Smart Wristband

To acquire information about their health during the experiment, each study object should wear Fitbit Smart Wristband. When purchasing experiment equipment in 2015, Fitbit Smart Wristband collected more information than other products of the same kind in the market, including steps, sleep quality, heart rate, flights climbed, mileage, and energy consumption (Figure 2-3).

■Software to receive GPS satellite location information

The project independently developed the "Community Residents' Behavior Monitoring Software V1.0" (software copyright of National Copyright Administration of the People's Republic of China 1100546) to receive GPS satellite location information and acquire location data (Figure 2-4; Figure 2-5).

Functional modules of the software include:

①GPS data acquisition and storage module: record and store location data;

②Upload the stored GPS location data to the server;

③Smartphone and Fitbit pairing analysis module.

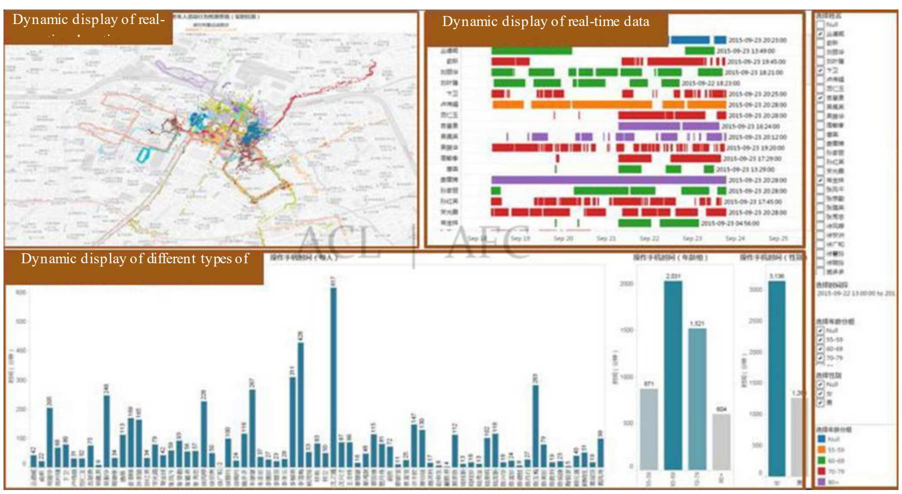
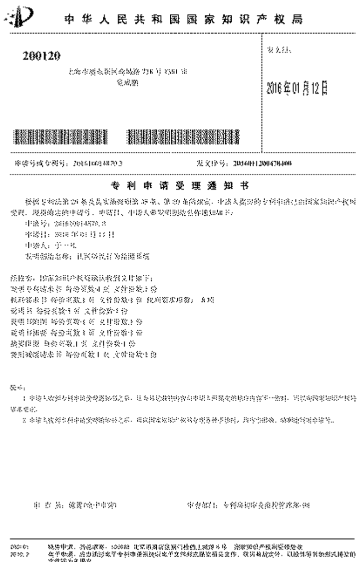


Figure 2-4 Data Receiving Interface of Community Residents' Behavior Monitoring Software V1.0

In order to evaluate the performance of the software and test the impact of errors caused by ionospheric delay, tropospheric delay, satellite clock error, satellite orbit and other factors on the accuracy of the location signal, we specially invited the GNSS research team from Tongji University to conduct testing before carrying out experiments (Figure 2-6).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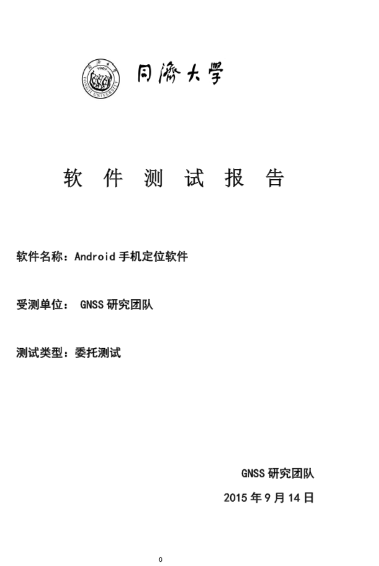

同济大学

软件测试报告

软件名称：Android 手机定位软件

受测单位：GNSS 研究团队

测试类型：委托测试

GNSS 研究团队

2015 年 9 月 14 日

Figure 2-5 Community Residents' Behavior Monitoring Software V1.0 Obtains National Software Copyright
Figure 2-6 Community Residents' Behavior Monitoring Software V1.0 Passes the Test of GNSS Team of Tongji University

(2) Study objects

The TJ New Village in Yangpu District, Shanghai was selected as the study base. The TJ New Village is a typical unit public housing community, which adopted the standardized housing design and community planning system. This type of community housing was built in large quantities across China from the 1950s to 1980s, laying a foundation for the applicability of findings. Moreover, these houses were mostly distributed to residents by their institutions (Dan Wei) as a welfare. As the residents' degree of ageing has been increasing over half a decade, the public houses became the main objects of elderly-oriented transformation project in urban communities in China.

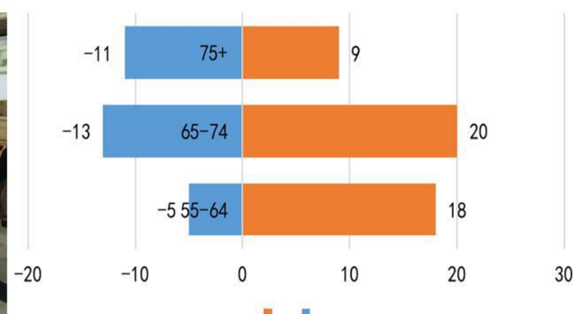

Figure 2-7 Plan of the Study Base -- TJ New Village Figure 2-8 Part Map of TJ New

In this study, TJ New Village's degree of ageing is as high as 38%, which means that more than one third of the community residents are 60 years old or above. In addition, the social and economic status of the residents living in this type of housing are highly similar. Most of the New Village communities are now located in the central city due to urban expansion and development. With complete supporting facilities in the surrounding urban environment, residents living in these communities have more travel options, which provides ideal experimental conditions for the study (Figure 2-7; Figure2-8).

Located inside the inner ring of Shanghai and adjacent to the campus of Tongji University, TJ New Village was founded by Tongji University in the early days. It is currently provided with some management services by Tongji University. At the beginning of the study, the project team organized publicity activities with Community Neighborhood Committees and team leaders of different buildings to recruit volunteers in each building. By doing this, it not only helped to enhanced the participation enthusiasm of residents, but more importantly, it could ensure that the elderly residents in the sample were evenly distributed in each group of the community. The project team eventually invited 80 elderly volunteers to participate in the experiment. 4 volunteers stopped or quitted for different reasons. Therefore, the complete data of the project was obtained from 76 volunteers. Additionally, first of all, the project balanced the gender and age groups of the volunteers in the sample; the volunteers participating in the experiment were all active and able to move freely; the subjects of this experiment didn't involve the elderlies who were in needs of counseling or nursing services (Figure 2-9; Figure 2-10).

2.2 Study design and experimental data

The daily living environment has an important influence on the lifestyles and behaviors of the elderly. To explore and measure this effect is the core issue of planning and design for promoting healthy and active aging through spatial intervention. The technical roadmap of the study can be summarized as follows: a. based on the spatial form, spatiotemporal intensity, and daily travel movement state of the elderly, the study deduced the daily travel behavior pattern of



the elderly in the community at the spatio-temporal scale and constructed the theoretical and analytical model of the elderly's activities in the community based on the trajectory data of daily activities of the elderly; b. based on the observation of the usage of facilities by the elderly within their walking distance, this study analyzed the spatial structure characteristics and environmental elements of the built environment if they were supporting or restricting elderly residents' daily activities; c. to explore what impacts do the levels of physical activity of elderlies and built environment have on the elderlies' daily outdoor activities based on the data recorded in the fitness wristband, such as of walking distance and intensity of physical activity, etc. Through these data, the research can study the relationship among the travel purpose, daily activities arrangement, and health behavior of the elderlies by using the trajectory data of different groups. The research variables for this study include the frequency of going out, the time of going outdoor, the duration of staying in a place, Point of Interest (POIs), route, the steps, intensity of physical activity, sedentary time, and other information provided by the fitness wristband.

The senior citizens participating in this experiment were asked to take an Android Phone and Fitbit Smart Wristband for 102 consecutive days from September 18 to December 28, 2015. The data generated by experimental equipment was uploaded to the database (SQL) via the Internet in real time, which will be recorded and classified by the system backstage. This study established a personal information file for each study object, including personal basic information and related information of corresponding equipment. Besides, the de-noising and compression of trajectory data were completed at the data pre-processing stage combined with multi-source data such as POI data and auxiliary geographic information data (Figure 2-11; Figure 2-12).

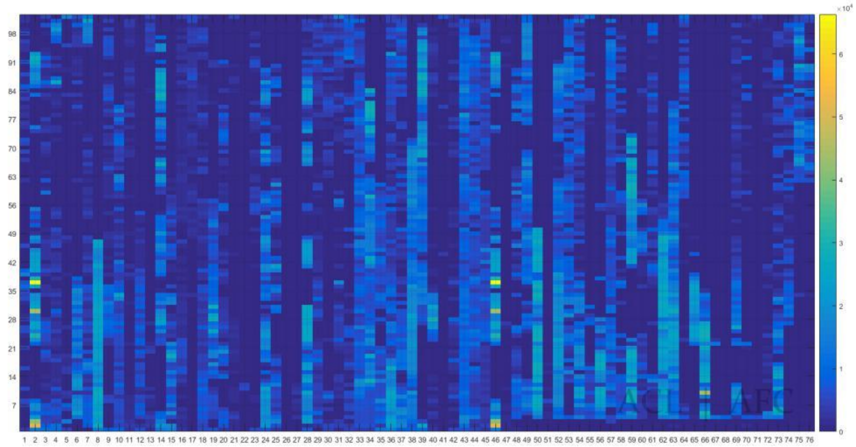


Figure 2-11 Trajectory Data Distribution Generated by 76 Senior Citizens in 102 Days

The X-axis represents the sample of senior citizens, while the Y-axis represents time.

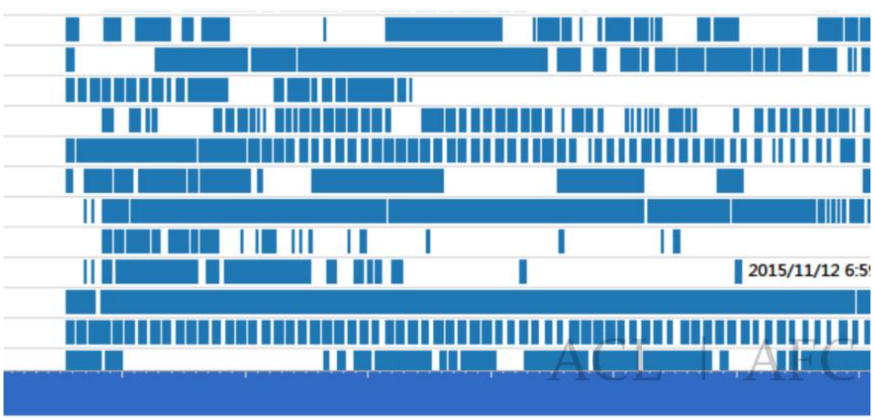


Figure 2-12 Data of Some Senior Citizens in the Sample Derived from the Smart Wristband

3. People-based findings: spatial behavior of the elderly in a community environment

3.1 Findings

The activity of daily life is a kind of habitual behavior that occurs regularly. The activity pattern can be identified by time distribution, travel characteristics, activity range, and the structure of trip chain. To understand and grasp the daily activities and spatial behaviors of the study objects is conducive to exploring deeper into the supports or restrictions which the elderlies have to face when living in the community for a long term. The other purpose of collecting these data is to encourage healthy behaviors by influencing their travel decisions. The research on behavioral space in the fields of behavioral geography, temporal geography, and urban planning provide the theoretical foundation for this research, while the study methods and analysis approaches adopt the innovative tools, such as quantitative analysis, behavior analysis, and spatial simulation in combination with the data characteristics of this study.

(1) Behavior model

Existing studies have shown that human travel has similar power-law distribution characteristics. Does the daily travel of the elderlies also have similar characteristics? The research collected the statistical data on travel frequency and travel distance of the elderlies in the community by different age groups. The analysis results showed that the travel distance distribution of the elderlies in the community showed a typical heavy-tailed distribution, which was consistent with the travel activity distribution of the population of all ages. However, the travel distribution of the elderlies has a slow decay rate and a long tail which means the probability of a large observed value is much higher than the prediction based on Poisson distribution. The travel distribution has intermittent characteristics in terms of the distribution law. The above findings indicate that the experimental data are true and effective, conforming to biological characteristics. Furthermore, it shows that the daily travel behavior of the elderlies has its own characteristics and its pattern subject to non-Poisson statistics (Figure 3-1).

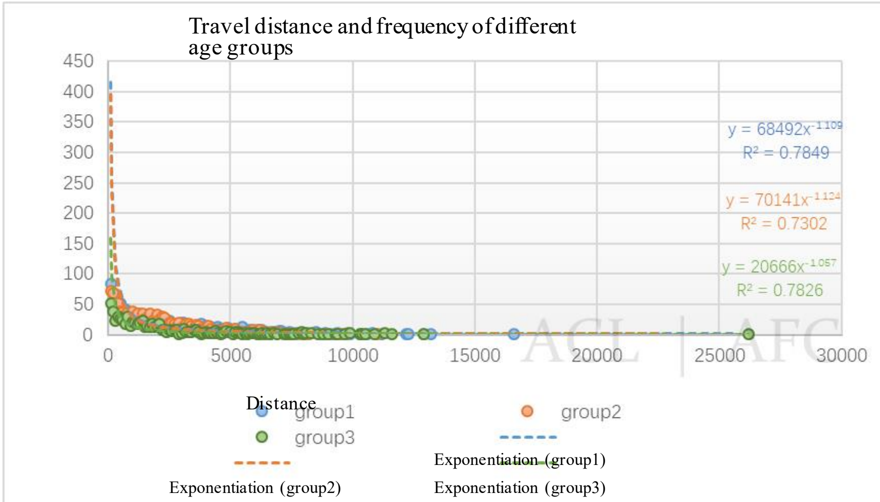


Figure 3-1: Travel Distance and Frequency of the Elderly in Different Age Groups
Group 1: 55-64, Group 2: 65-74, Group 3: 75+

Although all the study objects are from the TJ New Village, the differentiation of the elderlies' daily activities and behavior patterns is still quite significant. The following six senior citizens' activities in the community show this difference, which is heuristic for the actual impacts from residence, route, and facilities on the elderlies' travel (Figure 3-2).

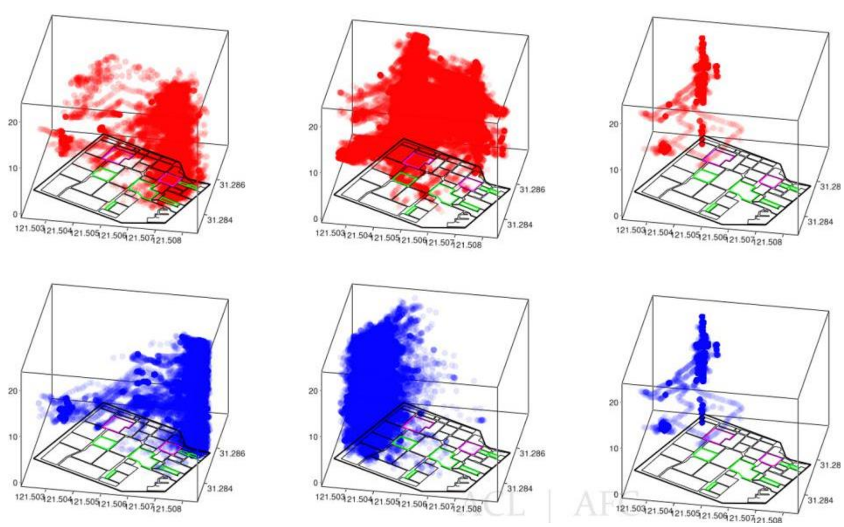


Figure 3-2 Difference in Spatial Range of Individual Travel of the Elderly within the Community
Red: Sample of three elderly women; Blue: Sample of three elderly men

(2) Travel characteristics

According to the GPS track data of the elderlies' daily travel, the following findings were made after collecting information about the travel methods by gender and age. Among all travel behaviors, the elderlies in the community mainly use walking and small proportion of mixed travel methods (such as the combination of walking, using motor vehicle, or non-motor vehicle). With the increase of age, the proportion of the mixed travel methods increases. The proportions of motor vehicle travel in older groups increases, which conforms to the natural law that the elderly's physical strength decreases as they get older. In different age groups, the proportion of elderly men who choose to walk is higher than those of the elderly women. In younger and older groups, the elderly women who adopt the mixed travel method are significantly higher than the elderly men. The proportion of elderly men who adopt the mixed travel method decreases as they get older (Figure 3-3).

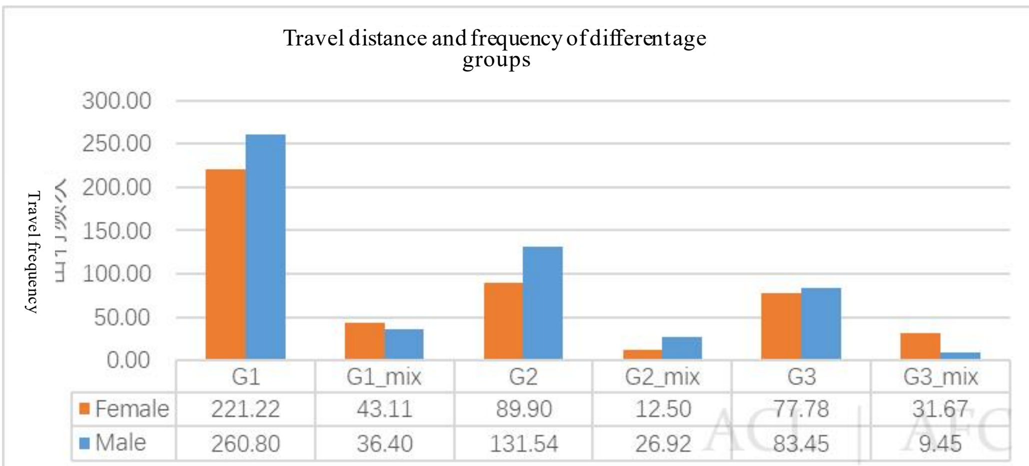


Figure 3-3: Travel Distribution of the Elderly by Age and Gender
Group 1: 55-64, Group 2: 65-74, Group 3: 75+

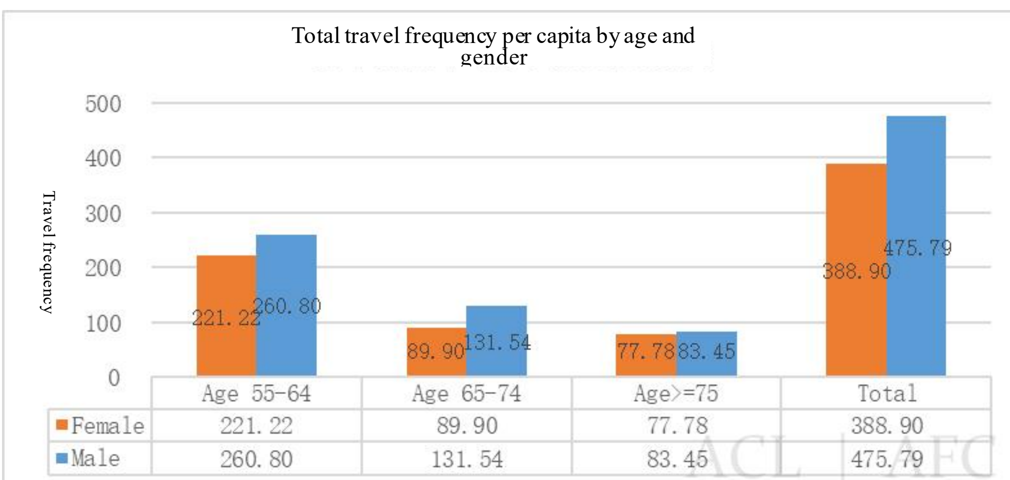


Figure 3-4 Travel frequency per capita by age and gender
Group 1: 55-64, Group 2: 65-74, Group 3: 75+

According to the total walking trajectory data of 76 study objects in the entire experiment cycle, the travel frequency obtained after standardization of the sample number within the group shows that on average, older people tend to have lower travel frequency. Among them, t in the age between 55 and 74, the per capita travel frequency of men is higher than that of women. However, in the age group of 75 years and above, there is no significant difference between men and women. (Figure 3-4).

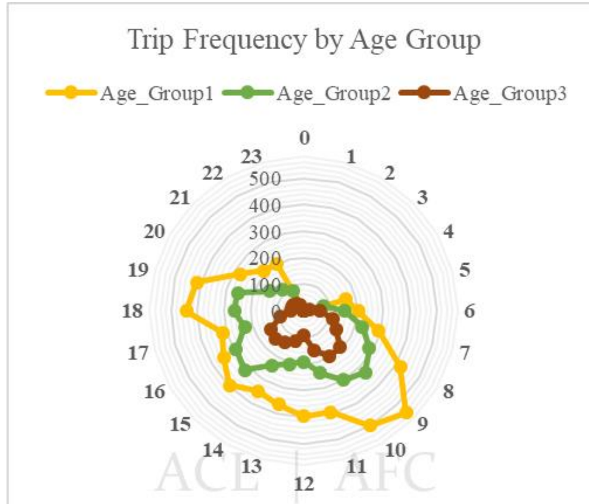


Figure 3-5 Travel time characteristics by

In addition, the earliest time when elderlies travel various in different age groups. Specifically, the active time of the study objects between the age of 55-64 starts earlier than those who are 65 and older (Figure 3-5).

(3) Travel range

Adding up the walking range data of 4 age groups of the study objects: 55 to 64, 65 to 74, 75 to 84, and 85 and above, the study found that the age group of 75 to 84 has the biggest walking range, followed by the age group of 65 to 74. Both groups greatly exceeded the age group of 55-

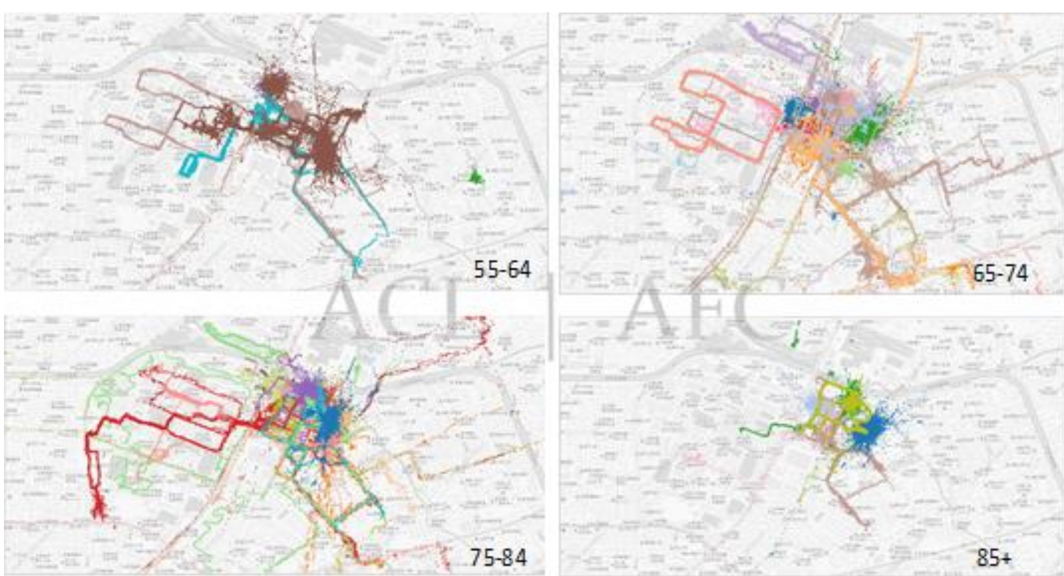


Figure 3-5 Travel scope by age

64. The result does not match the common opinion that the range of activities is inversely proportional to age increase. The walking range of the 55-64 years old is small. Their destinations are very concentrated. Combining the personal information of the study objects and the pre-survey questionnaires, the study found that although all the study objects are retired, some of them are still doing some paid works. Since the majority of the study objects are faculties from Tongji University, the daily travel pattern of some objects in the younger age group has the characteristics of pendulum. In addition, it is more common for elderly people in the younger group to take care of their grandchildren than those in the older group. Thus, their daily travel range is limited. Relatively speaking, based on the general inference, people who are 85 years or older would have the minimum travel range (Figure 3-5).

According to the daily travel range of individuals, the overall activity range of the elderlies in the community can be superimposed on the GIS map. The gradient from green to red in the figure shows the superposition intensity of trajectory data. It's not difficult to find that the daily activities of the elderlies mainly take place in and around the community. The destinations with a high frequency of visits by the elderly are distributed along urban roads around the community. The north side of TJ New Village is adjacent to the inner ring road (North Zhongshan Road). However, the elderlies' travel seldom occur in the north of the community, indicating that the high level traffic trunk road becomes the main barrier for the senior residents' daily travel. Part 4 of this report will discuss the activity space for senior residents in the community again from the perspective of space identification (Figure 3-6).

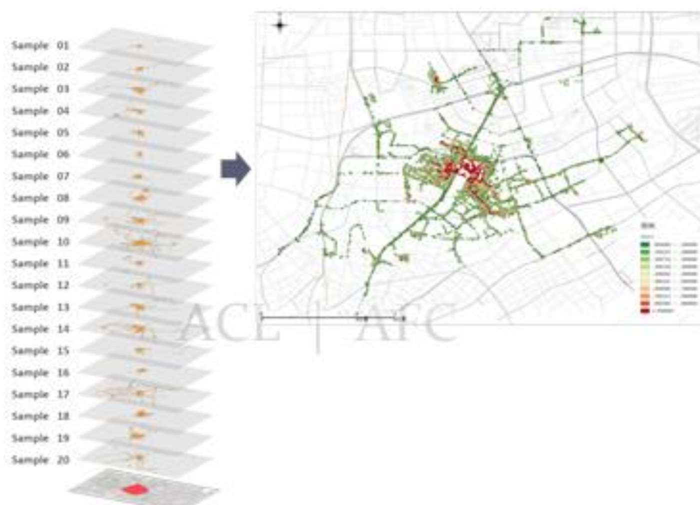


Figure 3-6 Superposition of Daily Activity Space Scope of the

(4) Trip Chain

Trip Chain refers to the whole process of people organizing their travel base on time and space for completing one or more activities. The information in the trip chain includes space, time, methods, and purposes. It creates a link between different travels as well as between travel and activities. It does not only have the potential to reveal the travel decision-making mechanism, but also directly affect the travel demand forecast and the spatial allocation of POIs. By understanding the length of the trip chain, the number of stops, and the complexity of activities, people can better understand how the space structure and facility layout built environment affect the daily activity pattern of the elderlies. This study is based on the data of a single travel trajectory of the elderlies. More specifically, it collected the high-frequency GPS information from the starting point to the ending point. The study found that the daily needs and lifestyles of individuals have a significant impact on the formation of the trip chain. The study objects can make over ten stops on longer travel chains (Figure 3-7).

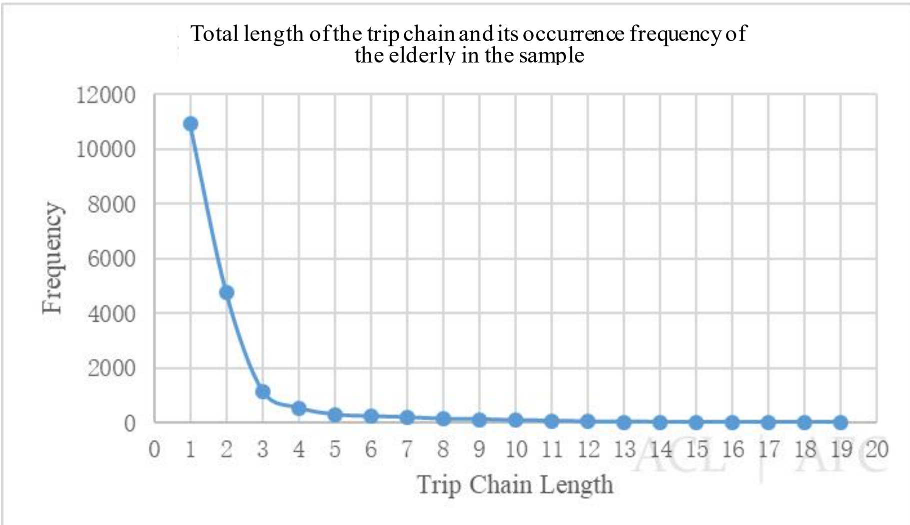


Figure 3-7 Length of the trip chain and its occurrence frequency of the elderly in the sample
x axis: Number of trip chain destinations; y axis: Length of the trip chain for a single trip

Trip chains are divided into the single-purpose trip and multi-purpose trip according to the number of stopping points during the trip. Comparing the number of trip chains of single-purpose and multi-purpose trips, it's found that single-purpose trips account for more than 50% of all trip chains (Figure 3-8). Among them, the older group is the highest among three age groups. The longer the trip chain is, the less elderlies travel (Figure 3-9).

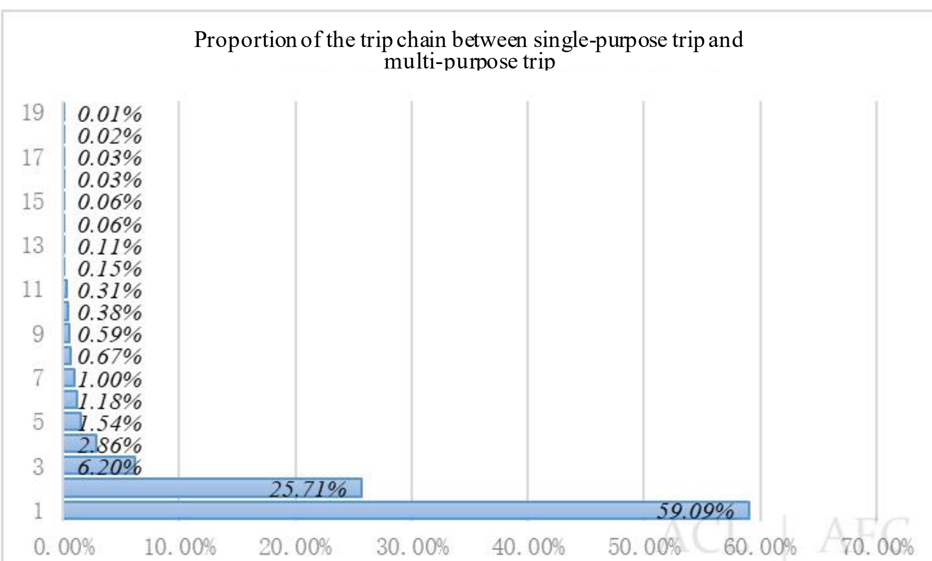


Figure 3-8 Scale Proportion of the Trip Chain between Single-purpose and Multi-purpose Trips

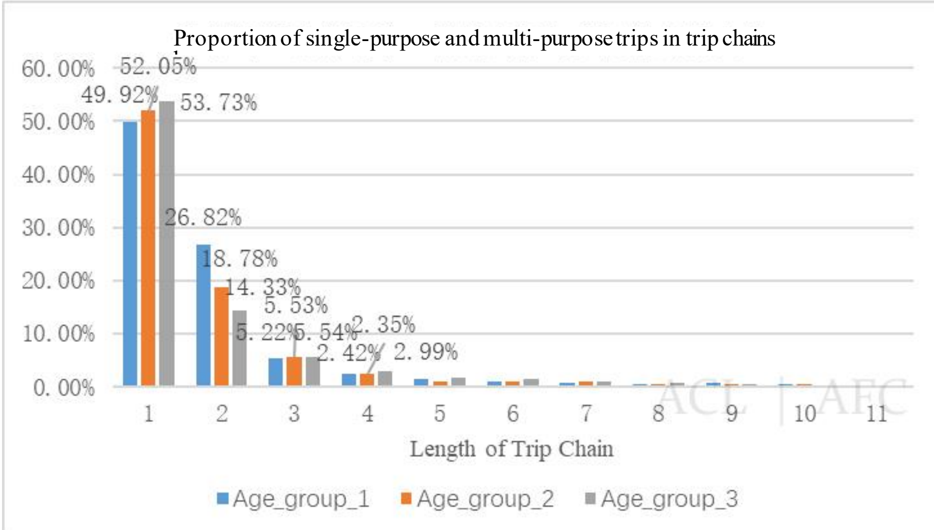


Figure 3-9 Proportion of Single-purpose and Multi-purpose Trips in Trip Chains by age Group 1: 55-64, Group 2: 65-74, Group 3: 75+

(5) Influence of climate factors on travel of the elderly

The study team collected and recorded the information on weather, temperature, and air quality during the experiment. According to the comparative analysis of travel activities of the entire sample, the total travel activities decline constantly with the decrease of temperature, which is manifested as the shortening of travel distance and duration. Good weather and air quality can encourage outdoor activities. Four peaks with a slow downward trend in the Figure 3-10 mainly correspond to one-day travels in warm, sunny, and good air quality conditions.

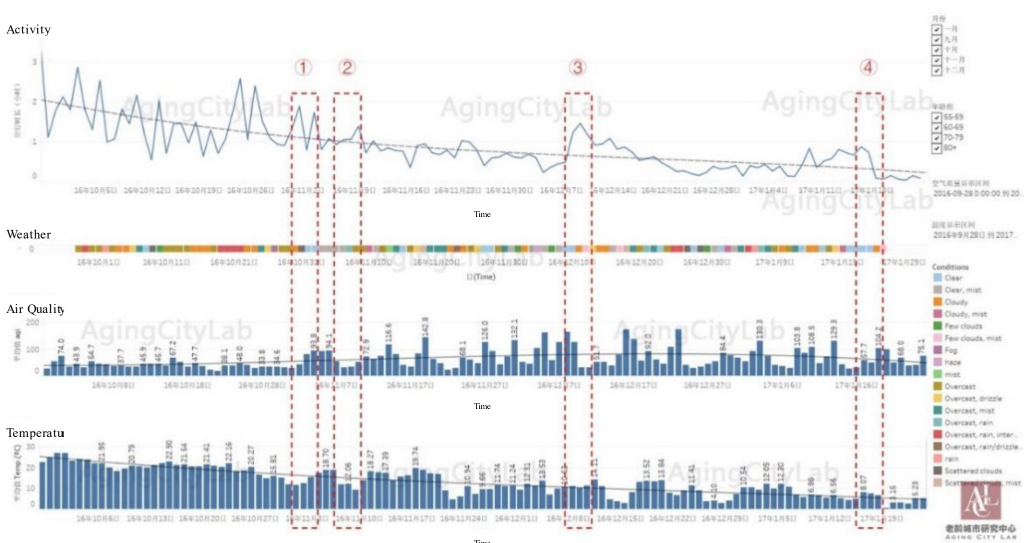


Figure 3-10 Influence of Climate Factors on Travel of the Elderly

3.2 Summary

The study proposes to turn the urban and community into a multi-functional community which will satisfy elderlies' needs for their daily travels, outdoor activities, and social interactions. It also suggest understanding the built environment through the types of activities, the duration of stays, and the scatter of destinations instead of through the types of construction land and the scale of facility which are used in the traditional planning methods. The retired elderlies use the community and surrounding urban environment as their main activity space. The characteristics and patterns of the elderlies' daily activity trajectory, sequence, and their allocation of time are important factors to evaluate the applicability of the built environment, the performance of facility services, and how elderly-oriented the community is.

Different from the perspectives when conducting research on the economy, society, and management, the behavior-based study emphasizes the understanding of behavioral selection and restriction process of individuals at the non-aggregate level. This is conducive for the study to reveal the process and mechanisms of interactions between individuals and the built environment.

4. Site-based findings: behavioral space of the elderlies in the community environment

4.1 Findings

The study finds that there are many connections between theories and practices of individual's daily life activities and spatial planning and design. The visualization of individual behavior space can help identify spatial behavior patterns of specific groups or individuals from a large amount of data. The visualization can also reveal the interactive relationship between people and the environment and explore the fields of environmental constraints and support, time and space as well as differences and commonalities. This study used GPS data of the elderlies' daily activities and established the trajectory database under GIS. It used the fuzzy clustering to classify spatial units and map algebra to conduct spatial superimposed analysis. It also used rasterization analysis, spatiotemporal prism analysis, path analysis, and other means to explore how the elderlies use the existing living environment and facilities to make up for the lack of understanding for the rigid functional space. The study presented the spatial structure based on the dynamic and refined data, which is crucial to explain and optimize the built environment through activities and behaviors.

(1) Daily activity space

In Section 3.1, we obtained the spatial range of daily activities of the elderlies in the community by identifying their daily travel range and compositing the superposition of individual's walking

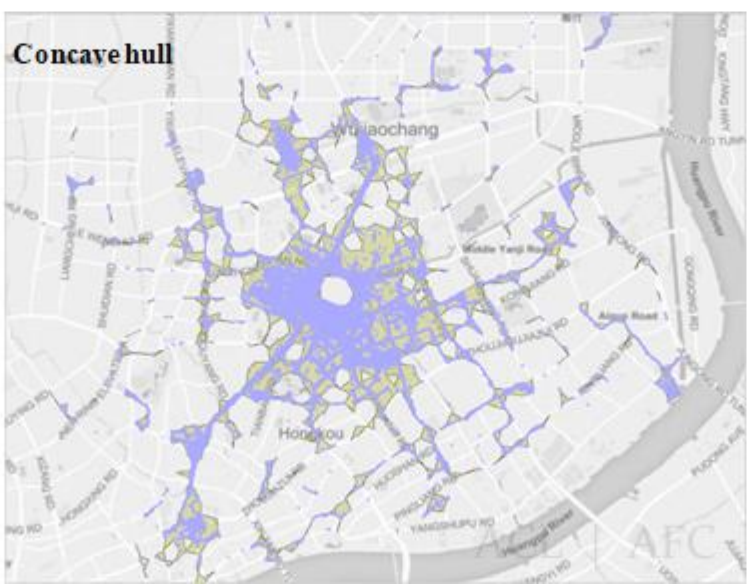


Figure 4-1 Scope of the Elderly's Daily Activities in the Community

range. We used the walking trajectory data as the source and provided a more accurate algorithm and recognition tool through PostgreSQL and the data visualization platform FME. Firstly, we processed the data, identified the spatial trajectory based on PostgreSQL database, and calculated the average walking speed of <=6.5km/h and the fastest walking speed of <=9km through GPS spatial data. Secondly, we used the Alpha Shape algorithm from the FME Concave hull module to generate the walking range polygons and realize data visualization. Among them, the "island" polygon was deleted in the final result set (Figure 4-1).

We found that Concave Hull algorithm was significantly superior to Convex Hull algorithm, when processing GPS data to identify the travel scope, although the latter is more commonly used internationally. The advantage of Concave Hull algorithm is that it can effectively reduce the impacts from the GPS abnormal data points, while the Convex Hull algorithm is easily affected by abnormal data points when conducting big data calculation. The latter will cause biases in the Convex hull range. Secondly, the boundaries of the space formed by Concave Hull algorithm form are clear, comparing those formed by the Convex Hull algorithm which are highly uncertain.

Based on the elderlies' daily activity range formed by the Concave Hull algorithm, we further found that maximum walking time for a single travel is 60 minutes. There is a significant decline in activities in the range between 30 to 50 minutes. Senior residents normally have continuous walking time within 15 minutes and 5-10 minutes walking time is the most commonly observed.

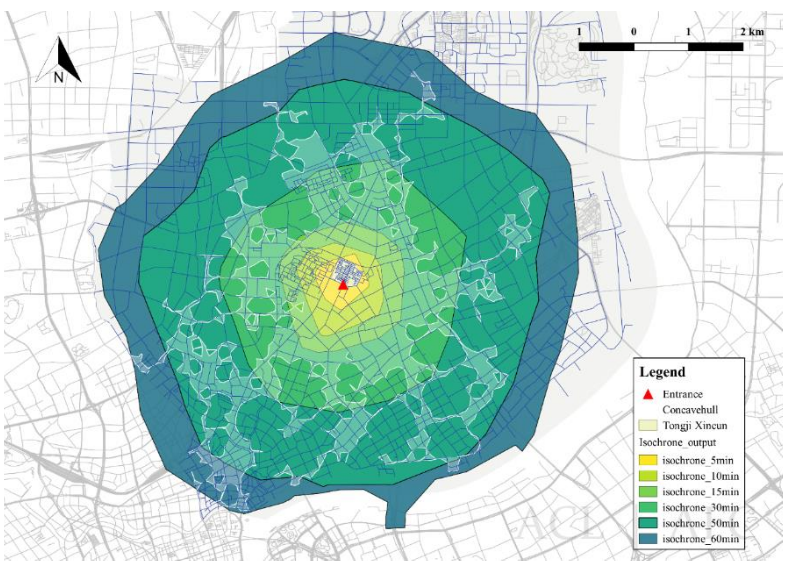


Figure 4-2 Scope of the Elderly's Daily Activities in the Community

(2) POIs frequently used

The most visited POIs in the built environment are important locations to be analyzed in planning and design. These locations do not only include public service facilities that meet daily needs of the elderlies, but other places in the living environment that attract people to stay, such as street green spaces, road corners, fitness equipment, and entrances & exits of the community. Understanding the use of POIs in the built environment by the elderlies is helpful to reasonably allocate the type, scale, and site selection of supporting facilities. By identifying new POI types, the planners would be able to better create the sense of place in the community and encourage more healthy behaviors.

The study superposes the POIs information obtained from Gaode Map on top of the GIS basemap. Then, the study uses the travel trajectory data of the study objects through clustering analysis to obtain a thermodynamic diagram. By comparing these two sets of data, we are able to filter the exact locations of the most visited POIs by elderlies. The results showed that, the most

Figure 4-3 Process of Obtaining POIs Frequently Visited by the Elderly in the Community

visited POIs by the elderlies have the characteristic of radial distribution around the community in terms of spatial layout. The radial direction is related to the location of entrances & exits as well as the layout of surrounding roads (Figure 4-3).

Located at the center of the city, TJ New Village is surrounded by relatively developed

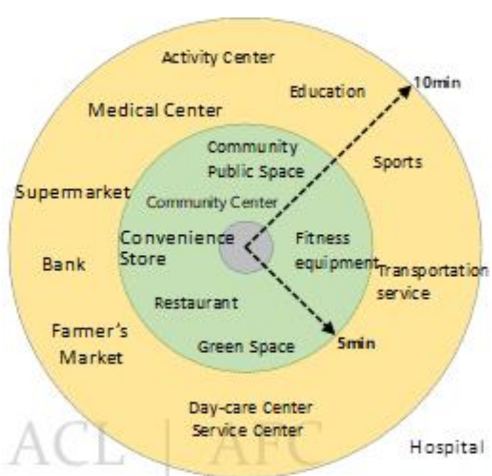


Figure 4-4 Types of POIs Frequently Used by the Elderly Figure 4-5 Behavioral Space of

facilities. When visiting POIs of the same type, people often have multiple choices. The study shows that closer travel distance is the main factor influencing the elderlies' preference for POIs. The more frequently POIs are used, the more significant the accessibility became. The types of the most visited POIs within a 5-minute walking distance include: Green spaces and community activity centers which are located within the neighborhood committee, outdoor fitness equipment, convenience stores, restaurants, and urban parks green space. The types of the most visited POIs within a 10-minute walking distance include: Banks, markets, supermarkets, drug stores, sports facilities, and community hospitals (Figure 4-4). Integrating the elderlies's trajectory data with the actual living environment can intuitively present the characteristics of the travel paths and the places where the elderlies often stay (Figure 4-5).

It's worth noting that the daily travel of the elderly living in specific communities is unavoidably constrained by the existing base conditions of the environment as well as the current layout of the facilities. It is necessary to speculate possible patterns through understanding more types of built environment.

(3) Use of public service facilities

Based on previous findings, the project conducted a further analysis on POIs within the maximum walking distance of 60 minutes. The result shows that the types of POI visited by study objects on a daily basis mainly include parks, green spaces, public service facilities, commercial facilities, and medical facilities. These POIs have high selectivity within the 60-minute walking distance. (Figure 4-6).

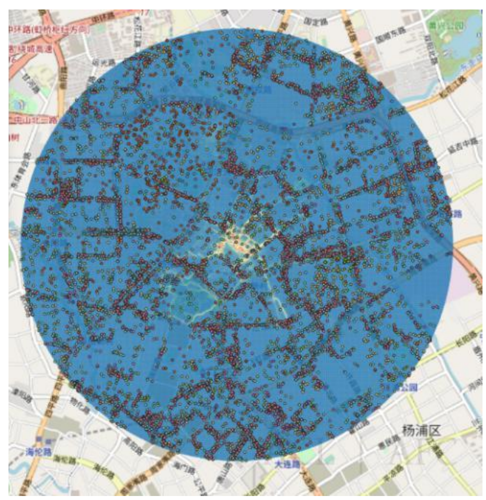


Figure 4-6 Distribution of POIs within Daily Walking Scope of the Elderly

According to the sorted data of the frequency of visit and the length of stay of the study objects in various public service facilities, the result shows that the accessibility has more impacts on elderlies' decisions than the size of facilities. It indicates that for the elderlies, completing the travel tasks is more important than the enjoying the service quality.

Taking the urban green space as an example, there are two district parks around TJ New Village: Heping Park and Luxun Park. Heping Park is within 15-minute walking distance. However, according to the clustering analysis based on trajectory data, the parks which are frequently visited by the elderlies/ study objects in the community are Siping Science and Technology Park and Songhe Park whose scales are relatively small and the facilities are not as complete. It is notable that although Siping Science and Technology Park and TJ New Village are separated by only one road, this road has a wide road restriction line and heavy traffic. Many elderlies feel stressed to cross the road, which may be the reason why the elderlies spend less time at the Siping Science and Technology Park than at the Songhe Park which has longer travel distance. From this example, we can see that safety and comfort are also important factors influencing elderlies when they choose between similar POIs (Figure 4-7).

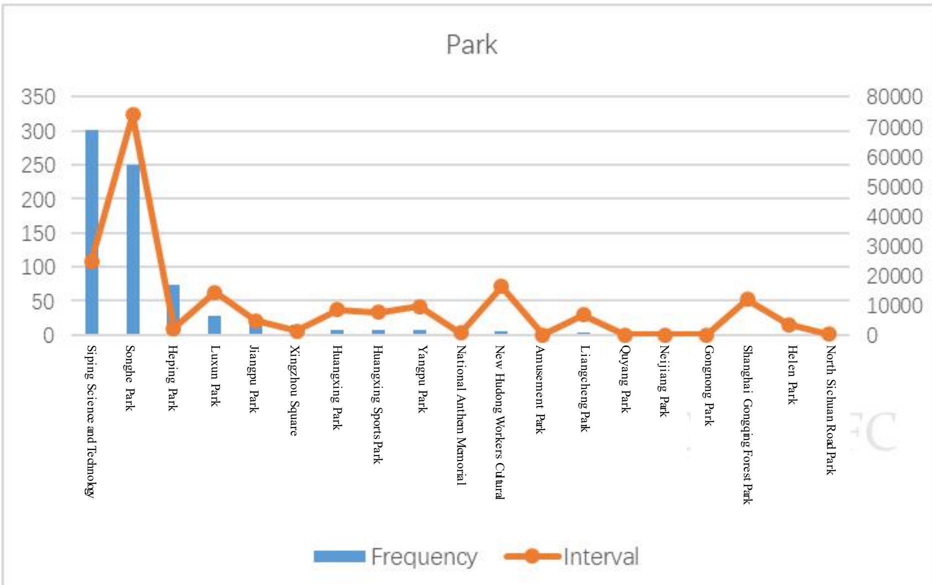


Figure 4-7 Use of POIs of the Urban Green Space Type

(4) Case study of medical treatment and medical facilities

Seeking medical treatment, shopping, leisure, fitness, and social communication are the main daily life behaviors of the elderly in the community. The locations where these behaviors occur, such as medical and health institutions, commercial retail, markets, urban green spaces, public service facilities, are the main planning and design objects within the community's built environment. This part of the study discusses the algorithm to identify the elderlies' behavior of seeking medical treatment, as well as the characteristics of their behavioral space, such as the type of facilities and the spatial distribution (Figure 4-8; Figure 4-9).

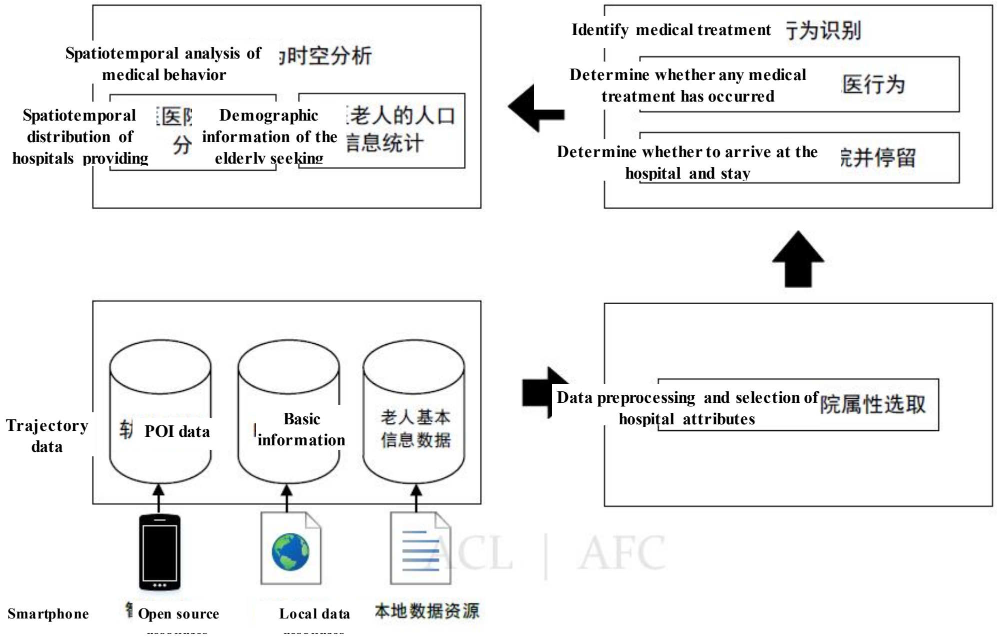


Figure4-8Analysis framework for the elderly to seek medical behavior

算法 1：基于老人轨迹数据的就医识别算法

输入： 共 N 位老人，第 i 位老人的移动轨迹 $\tau_i \in$ oldManTrajectory,

第 i 位老人的基本信息 $OI_i \in oldManInfo$

共 M 家医院，第 j 家医院 $H_j \in HospitalList$

输出： 识别出老人访问医院的轨迹并记录 trajectoryRecorder

FOR each trajectory point τ_{ik} in τ_i

isInArea ← isInBoundary(H_j, τ_{ik}); //判断轨迹τ_i的第 k 个轨迹点在Hospital$_j$内

IF isInArea is false or leaveTime ≥ T_{leave} **THEN**

IF $\Delta t \geq T_{stay}$ **THEN**

trajectoryRecorder ← $recordThisTraj(H_j, OI_i, \Delta t)$; }

ELSE IF isInArea is ture **THEN**

addHospitalnfo(τ_{ik}, H_j); //对此条轨迹加入就医医院的信息

$addTheTrajectory(\tau_{ik})$; //老人在这家医院中，存储此轨迹记录

ELSE //老人的"假离开"现象的处理

this elder deceiptivly leave from the hospital;

IF the last $\Delta t \geq T_{stay}$ **THEN** //判断最后在 POI 内的停留时间是否满足就医条件

trajectoryRecorder ← $recordThisTraj(H_j, OI_i, \Delta t)$;}

Return trajectoryRecorder

Figure 4-9 Algorithm to Identify Medical Treatment Based on the Trajectory Data of the Elderly

According to the study, the elderlies often go out in the morning and afternoon. The purpose-driven travels, such as seeking medical treatment, mainly happen in the morning and they mainly engage in activities within the community in the afternoon with the travel frequency showing an upward trend over time. Distance is the primary factor that affects the elderlies when they access healthcare facility related POIs. According to the pre-survey questionnaire, most of the elderlies in the sample suffer from more than one chronic disease. Follow-ups, medicine pick-up, and medical treatment are main purposes for elderlies' daily travels. The community hospitals can meet daily medical needs of many elderly people. (Figure 4-9)

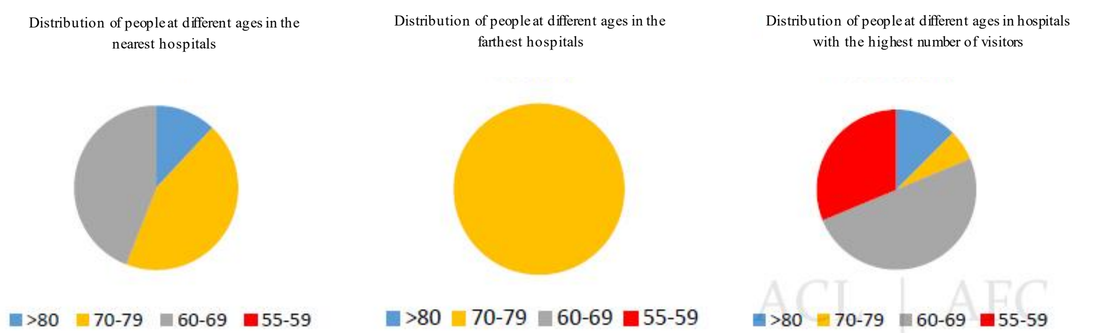


Figure 4-9 Spatial Characteristics of the Elderly's Behavior of Seeking Medical Treatment in TJ New Village (by Age)

(5) Selection and preference of travel routes

Figure 4-10 shows the routes used by the elderlies in TJ New Village according to the walking trajectory data. Firstly, the road inside the community (route 1) is the only way for the senior residents to go out, pointing to the entrance of Fuxin Road which is most frequently visited by people. Although TJ New Village has three entrances and exits, the entrance and exit of Fuxin Road is close to many commercial, cultural, catering facilities, and bus stations. One of the two entrances and exits faces the main traffic road, while the other is near the subway station and the main building of School of Economics and Management, Tongji University. Nevertheless, the section form of route 1 is the same as other roads inside the community. Thus, the density of surrounding service facilities plays an important role in the elderlies' selection of travel routes.

Route 2 (Zhangwu Road), Route 6 (Fuxin Road), Route 7 (Anshan Road), and Route 8 (Jinxi Road) are urban branches with dense facilities on both sides, such as the markets, fruit stores, restaurants, and drug stores. TJ community's entrances are located on Zhangwu Road, and plenty of shade trees are panted on Anshan Road, this made the two roads more commonly used.

Route 3 (Siping Road) is an eight-lane arterial road, featuring heavy traffic and fast speed. Tongji University and TJ New Village are located on both sides of Siping Road. Most of the elderlies who use this road usually go to Tongji University and the park on the other side. Due to the distance to cross the main road is long, many elderly people need to wait for two green lights on the island at the center of the road to cross the road. Senior residents have poor walking experience on this road.

Route 4 and Route 5 are main roads inside Tongji University and Siping Science and Technology Park. These two roads full of shade plants on both sides are pedestrian-oriented. They are also served as the main routes for senior residents to walk and exercise.

The study suggests that the routes which are frequently used by the elderlies should be equipped with barrier-free facilities. Convenience facilities and green spaces should be built to facilitate living and communication for senior residents. To ease the shortage of public green space in the central urban area under high-density housing situation, it is necessary to make a full use of green spaces affiliated with the units/companies near the community, so as to provide fitness and communication space for senior residents.

Public facilities in the urban environment around the community are the main motivations for elderlies to make decisions on the travel direction. Furthermore, the physical environmental conditions of the road also affects how elderlies use the roads. Convenient facilities on the sides of branch roads should be set up along with the barrier-free design, leisure facilities, and service

Figure 4-10 Main Routes and Street Spatial Characteristics of the Elderly' s Daily Travel in TJ

facilities for the elderly. This is to make the urban environment more elderly-friendly. Therefore, the surrounding streets of the sample community have great room for improvement.

4.2 Summary

A living space carries all the continuous activities of individuals in time and space. Restricted by research methods and data collection, previous studies have difficulties to make breakthroughs. This part takes the behavioral space of the elderlies as the study object, and shifts the study perspective from specific travel behaviors, such as commuting and shopping, to a large number of repeated and seemingly irregular travel behaviors in daily life. By utilizing the PostgreSQL and data visualization platform, this study provides a new method to identify activity space based on trajectory data. It tries to present the spatial dimension of the elderlies' daily activities in the community with simple and applicable Concave Hull algorithm. The study also uses the information of most visited POIs and the trajectory data for speculation reversely on how supporting facilities and routes affect the travel behaviors of the elderlies. In addition to answering the traditional question "Where does the behavior happen," the study also tries to answer the questions "Why does the behavior happen in this place," "Whether the behavioral space of the elderly is different from that of residents at other age groups in terms of characteristics," and "What role do the built environment and existing facilities play in daily travel of the elderly." The exploration based on behavioral space makes it possible to understand the built environment through people's decision-making and space restriction, and also to reveal the internal mechanisms of human-space interaction.

5. Findings based on data from smart wristbands

5.1 Findings

Based on Fitbit wristbands, the study analyzed the data collected from October 8 to November 9, 2015, in total 30 days. The data of all samples is still being cleaned up. Two main research topics which were completed include: First, analyze the differences in the activity level and the intensity of outdoor activities of the study objects by using information on the steps, distance, and energy consumption; second, analyze how the different floors the study objects live on impact their outdoor activities through the record on flights climbed.

(1) Outdoor activity level and intensity

Walking is the most popular outdoor exercise for elderlies. When walking, 60%~70% of human's muscle groups participate in this action. Walking consumes a large amount of body energy. It also requires the support and coordination of multiple organ systems, including the respiratory system, circulatory system, nervous system, and musculoskeletal system. Therefore, the walking speed has become the main indicator used to evaluate the health status of elderlies. The study measured the average walking speed of the study objects by age and gender according to the walking distance and the number of steps in their daily travel. The statistical results show that: a. The walking speed of the study objects is within the normal range; b. the walking speed of men and women tends to slow down as they get older; c. men in the same age group walk slightly faster than women (Table 5-1) (Figure 5-1).

Table 5-1 Walking Speed of the Elderly by Age/Gender (unit: m/s)

Age group	Female	Male	Health reference value
55-59	0.9323	0.9315	0.6-1.3
60-69	0.9185	0.9324	
70-79	0.9062	0.9166	
80+	0.8629	0.8989	

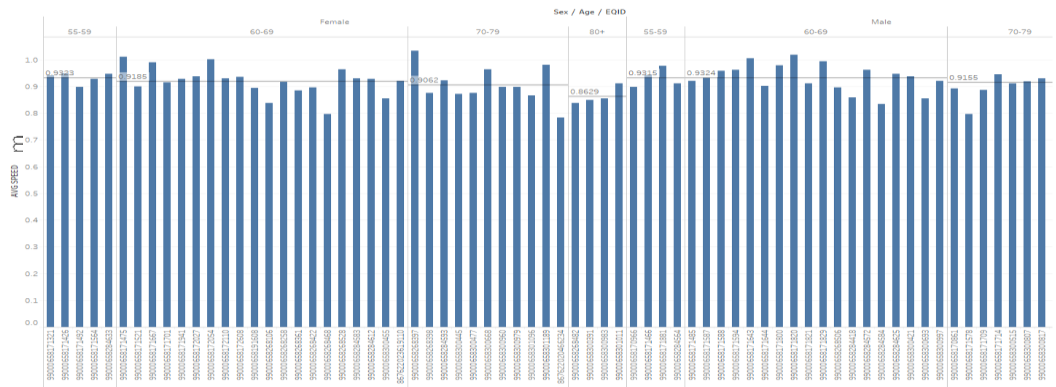
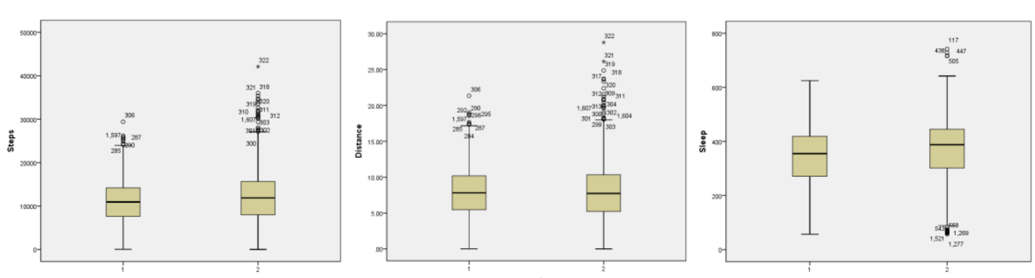


Figure 5-1 Walking Speed of the Elderly by Age/Gender (unit: m/s)

The study objects walk 11,900 steps per day at the walking distance of 8.06 km. This activity level is about twice of the minimum activity level per day for elderlies recommended by the Health Department, which is 6,000 steps per day. The higher activity level may be because the data was collected in autumn. Due to the appropriate temperature and climate, elderlies tend to spend more time outdoors. Through combining the trajectory data, the study found that compared with October, the activity level of the study objects decreased significantly in September and December. From the perspective of encouraging healthy behavior, providing a comfortable physical environment for elderlies in the community can effectively increase their motivation to go out, such as the cultural activity facilities that are suitable for meeting and interaction, as well as the elderly-friendly shared public service facilities and public space.

According to the energy consumption level during exercises, the study objects spend average 63 minutes on moderate to intense activities, 234 minutes on low-intensity activities, and 705 minutes in sedentary every day. Elderlies spend 392 minutes in bed per day on average, of which the sleep time is about 360 minutes.

Overall, women in the study have higher activity level than men, but they mainly engaged in low-intensity activities. Men in the study engaged more in activities with moderate intensity or above. Women in the study walk 12,400 steps per day on average, comparing to 11,100 steps for men, with walking distance of 8.14km, comparing to 7.92km for men. However, women in the study spend 59



minutes per day in activities with moderate intensity or above on average, which is less than the men who spend 71 minutes per day. In terms of sleep, women in the study have an average sleep time of 370 minutes per day, longer than the men's sleeping time which is 341 minutes per day (Figure 5-2).

Figure 5-2 Comparison of Mean Daily Steps, Travel Distance and Sleep Time of the Elderly by Gender

Group 1: Elderly men Group 2: Elderly women

In terms of age, the activity level of the study objects gradually decreases, and their sleep time gradually decreases with the increase of age. Firstly, the average daily steps and walking distance of elderlies will slowly decrease with age. For the group under 60 years old, it is 13,100 steps/8.78 km on average; for the age group of 60-70 years old, it is 12,300 steps/8.26 km on average; for the age group of 70-80 years old, it is 11,400 steps/7.67 km on average; for the group above 80 years old, it is 11,200 steps /7.77 km on average. This trend follows to the basic assumption that people's physical strength declines with the age increases.

The average time our study objects spend in low-intensity activities per day also tends to decrease with the increase of age. For those who are under 60 years old, it is 272 minutes; for those who are between 60 and 69 years old, it is 235 minutes; and for those who are between 70 and 79

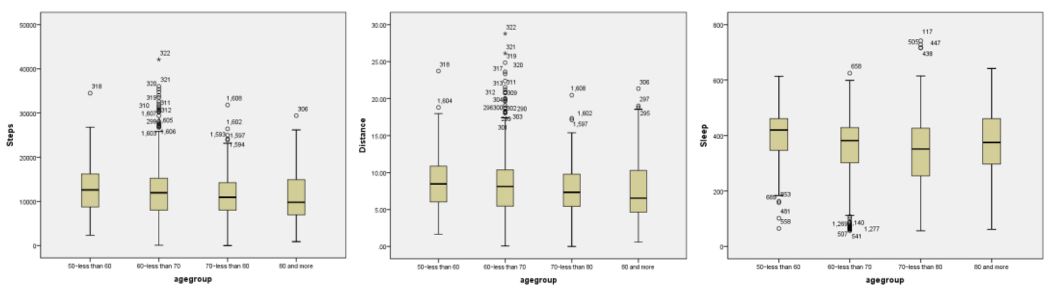


Figure 5-3 Comparison of Mean Daily Steps, Travel Distance and Sleep Time of the Elderly by

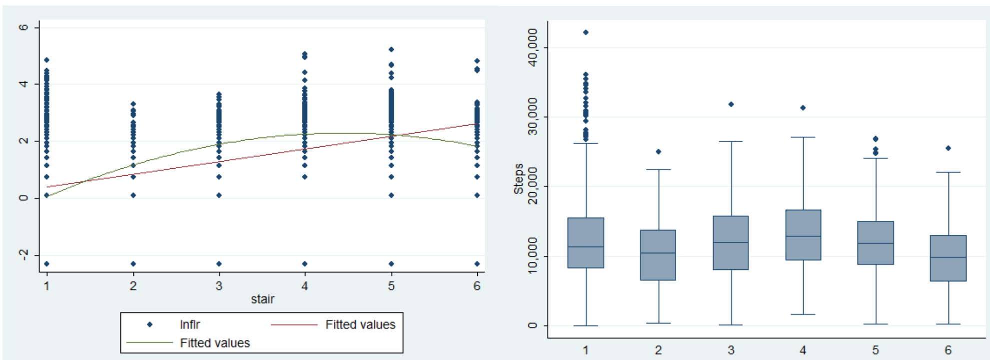
years old, it is 233 minutes. However, it is 680 minutes for those who are over 80 years old. This is may be because of the small number of samples over 80 years old in the total sample, requiring further explanation.

The average sedentary time of elderlies progressively increases with age. For those who are under 60 years old, it is 666 minutes; for those who are between 60 and 69 years old, it is 708 minutes; for those who are between 70 and 79 years old, it is 728 minutes; and for those who are above 80 years old, it is 206 minutes, which is an abnormal value. The average sleep time of elderlies, on the other hand, decreases with age. For those who are under 60 years old, it is 399 minutes; for those who are between 60 and 69 years old, it is 361 minutes; for those who are between 70 and 79 years old, it is 338 minutes; and for those who are above 80 years old, it is 372 minutes, which is an abnormal value) (Figure 5-3).

(2) Influence of the Floors Where the Elderly Live on Their Outdoor Activity Level

The study used the activity level and flights climbed data collected from fitness wristbands as well as the information such as address and health status of the study objects through questionnaires. The data were preprocessed with MATLAB and analyzed with Stata and SPSS.

The study found that the floors where the elderlies live have influence on their activity level at the vertical height. The activity level of the study objects who live on Floor 1-3 increases by floor. The activity level tends to be stable after above Floor 4 and then declines. According to changes in the overall activity level, Floor 4 is also an inflection point for the changes. This



indicates that Floor 4 is also the inflection point that affects outdoor activities of study objects. When living on Floor 4 or above with no elevator, the study objects have lower travel frequency and activity level (Figure 5-4).

Figure 5-4 (Left) Relationship between Vertical Activities and the Floors Where the Elderly Live X-axis represents the number of floors, while Y-axis represents the number of floors climbed per day (based on natural logarithmic deformation data).

Figure 5-4 (Right) Relationship between Total Activity Level and the Floors Where the Elderly Live

The study suggests that when a resident building has more than four floors, they should be required to build an elevator, rather than seven according to the existing technical standards. After carrying out research in other communities in Shanghai for many years, the team found that many elderly people living on higher floors of multi-storey residential buildings would take the initiative to reduce their trips. Some of them even stay at home for years, leading to a rapid decline in physical and mental health. However, appropriate environmental challenges are also beneficial for maintaining the physical functions of elderlies. Elderlies can climb stairs for exercise if their physical conditions allow. In this experiment, elderlies who live on Floor 1 don’t show absolute advantages in activity level and travel frequency, but elderlies living on Floors 2 and 3 overall have higher outdoor activity level. However, as they get older, the physical function of elderlies continue to decline. Therefore, it’s still necessary to build barrier-free facilities which are suitable for senior residents.

In summary, it is necessary to install elevators or other lifting equipment in multi-storey residential building which has high degree of aging. Also, in new residential areas, buildings that have more than four floors are suggested to install elevators. Lastly, residential buildings with elevators should pay attention to setting daylighting facilities, lighting, barrier-free handrails, and other facilities between different floors so that senior residents can have multiple choices.

5.2 Summary

As the intensity is directly related to the effect and safety of activities, it is important for elderlies themselves to control their activity level within an appropriate range through grasping their heart rate, energy consumption, and walking distance on a timely basis. The elderlies who participated in the experiment have formed the habit of observing their own health information when wearing the wristbands. They put forward relevant questions to researchers during the weekly health consultation and equipment maintenance sessions provided by the research group. They would adjust their activity level according to the reference range provided by researchers. The team summarized the weekly activity level, heart rate, sleep quality, and other information of each senior residents who participated in the study into a report and provided these reports to them. At the same time, they invited graduate students from School of Public Health to provide the elderlies who were in the study with blood pressure measurement, report interpretation, and knowledge consultation on exercise and health. Many of the elderlies hoped they can continue to receive the data of smart wristbands and weekly exercise reports after the experiment. From this, we can conclude that keeping informed and achieving goals are important to promote healthy lifestyles among elderlies. Wearable smart devices have a broad prospect in terms of providing health information services and early warning for elderlies. It is not only beneficial to encourage elderlies to scientifically arrange activities and exercises based on their own conditions, but to identify health risks and take interventions in a timely manner.

6. Conclusions and Suggestions

Since the beginning of this century, studies in spatial and social fields have unprecedentedly focused on exploring human subjectivity and emphasizing the causes and consequences of spatial processes. The research priority has also shifted from the allocation of resources to the characteristics of human's spatial behaviors and their decision-making process. This research is at the forefront of this field globally, the team has been invited to share the study at Harvard University and MIT in the United States, the University of Sheffield and University of Edinburgh in the United Kingdom, the University of Hong Kong, Hong Kong Polytechnic University, and many well-known universities in mainland China.

6.1 Conclusions and Suggestions

The units who carry the project are the Aging City Lab and the Age-Friendly Community Research Centre led by Professor Yu Yifan from the College of Architecture and Urban Planning, Tongji University. The research team is composed of interdisciplinary personnel from geographic information and mapping, public health, and big data and software. In this study, researchers used smart devices to collect GPS spatial trajectory data and health data. The monitoring on 76 elderly people in TJ New Village for 102 days continuously was completed, and the research results were integrated and analyzed through data mining, data fusion, and analysis modeling. The contributions of this study can be summarized as the exploration of scientific problems, innovative research methods, and suggestions on planning and application.

(1) Exploration of scientific problems

As the spatial carrier of daily life activities for most senior citizens, the built environment in the city and community provides elderlies with facilities for public services, transportation, leisure, fitness, and other functions. However, there are also constraints that hinder the elderlies' daily life and social activities. The existence of these constraints may be attributable to the ignorance of the activity needs of specific groups or the misjudgment on activity patterns and behavior characteristics. This study takes the senior residents as the study objects, and uses the data generated by smart devices to reproduce the behavior model and decision-making process of individuals and groups in a truthful and three-dimensional way. This study attempts to discuss the structural relationship between spatial behavior and behavioral space.

The study reveals that even under the highly consistent social and environmental base conditions, there are still significant differences among the elderlies' daily life activities, mainly including the age and gender differences. This indicates that the elderly-oriented construction and renewal of the built environment should focus on the commonality of elderly groups as well as the applicability and safety of environmental facilities. On top of that, we should pay attention to the differentiated features within the group so as to improve the life quality of elderlies.

The findings shows that the decision-making process of elderlies is based on the individual's selective understanding, learning, and organization of external information. The decision-making result is determined not only by the location-born opportunity and environmental constraints, but also the individuals' cognition of space. Individual differences in cognition, ability, and decision-making are important elements to understand the patterns of spatial behavior. In terms of planning, design, and resource allocation, we should consider shifting from emphasizing statistical population to individuals or groups under specific conditions with different cognitive abilities and health.

As indicated by the study, the behavioral space of elderlies is the area containing all accessible activity sites under spatiotemporal constraints. The patterns of their travel activities are related to the starting point, effective interval, travel time, and the physical conditions of individuals. Most existing studies in this field focus on single-choice behavior and rarely extend to the analysis of real travel behavior from the aspect of trip chain and arrangement of the daily activities. This study discusses the characteristics of elderlies' activities in the community through spatiotemporal prism and routes. It can contribute to grasping the scope, characteristics of the distribution, and preferences of elderlies' daily travels more comprehensively. At the same time, through the linkage analysis of different types of trips and target POIs (such as business hours), it is conducive to gaining a deep understanding of the reaction pattern of behaviors to environmental information, the arrangement of the trip chain, and daytime activity sequence.

The researchers proposed that time is an important dimension to analyze the efficiency of built environments. The study introduces the analytical dimension of time on the basis of spatial resources. It uses the dimension of time to understand the spatial resources and takes time as another resource of the community's environment and facilities. The spatiotemporal distribution of outdoor activities and environmental facilities used by elderlies in the community has a significant peak, rather than a homogeneous distribution and full-load operation. The occurrence of peak value is subjected to a stable pattern.

The lifestyle of elderlies is essentially the result of interactions between people and the environment. No matter the Fit Theory, Competence Theory, or Adaption Theory, they see that all the purposeful behavior of completing a life task as the result of human and environmental infiltration. It means that in an active lifestyle, the environmental stimulation should be fully utilized for elderlies; on the contrary, a negative lifestyle suggests that either the built environment does not provide enough support for elderlies or it is beyond their capability. The lifestyle of elderlies, especially the behaviors and concepts, is formed during their interaction with the physical and social environment. This interaction presents human's needs and values. It also serves as a medium for people to intervene, understand, and transform the environment. People can seek improvements and strategies through identifying the contradiction between human and the environment.

It's noteworthy that the experiment did not involve seniors with self-care difficulties and who are unable to travel independently. We believe that we should organize social services to provide targeted support for groups in need of exclusive services.

(2) Innovative study methods

The improvement in data collection and analysis methods brings new possibilities for optimizing planning methods and intervention strategies. Although micro-data investigation has been attracting more attention since the beginning of this century, the main tools adopted so far are still limited to behavior blog and investigation. Using GPS data and network data to explain and solve problems related to the built environment is still developing. Personalized trajectory data is even more difficult to obtain. New data sources make modeling, simulation, and visualization analysis possible. Thanks to this, the elaboration of the mechanism and the systematic analysis of multiple factors have made a big step forward.

By presenting the internal space structure and people's behaviors intuitively, we can carry out recognizable features and patterns of massive data, such as the visualization of spatial elements. For traditional methods of describing human behavior based on two-dimensional maps, it's an important leap forward. The geographic information system (GIS) expands spatial knowledge from geographical concepts, such as location and distance, to structural relationships, such as proximity, aggregation, and isolation. The GPS trajectory data creates potential conditions for exploring the formation process of these structural relationships. When analyzing behavior, our study shifts from result-oriented to process-oriented Through understanding the process, we tries to explain why and how spatial behavior occurs. The study also explores the measurement model and innovative algorithm for the spatial-behavioral interaction mechanism, and reveals the characteristic, preference, selection, and decision-making process of individuals.

The research shows that the accessibility at the substantial space level is limited by spatiotemporal prisms, potential routes, and other aspects. By exploring the patterns, we can simulate various possibilities of daily activities in a specific environment. In addition to time and space limits, relative analysis should also consider the influencing factors such as the rationality of trip chain, travel habits, and route dependence. However, the simulation of adding human factors to activity sequences is much more elaborate and complex than previous spatial analysis methods. In this study, we try to figure out the matching relationship between the elements in a specific built environment and people's activities and realize the tracking and presentation of individual multi-purpose trip chains. Then, we probe into solving the problems that can't be addressed the summary statistical model through refined trajectory data and the quantitative analysis model. The range of travel, activity patterns, activity types, spatial preference, and travel decision which are revealed in this study all play a great role in simulation and prediction for future environment planning and intervention. These information are useful references when optimizing resource allocation, building elderly-oriented environmental facilities, and providing elderly-oriented conditions during community renewal.

Next, the study plans to build a behavioral decision model based on refined trajectory data to meet the requirements of application and prediction. The corresponding computational process model focuses on analyzing the multi-level and structural characteristics of behavioral decision-making. We believe that the development of the relationship model will further assist individuals and groups in making wise travel decisions. Moreover, this model can be applied for planning and individual decision-making information systems.

(3) Suggestions on planning and application

The built environment is a collection of activities, behaviors, reactions, and interactions of elderlies. We explore how the elderly use different sites and facilities inside and outside the community, how they choose and respond to environments, and how they arrange the activities and allocate time accordingly. Then, we can better evaluate and discover the policies and measures that can optimize the urban environment.

The daily activities of elderly residents constitute a dynamic social and behavioral space superimposed on the substantial space. They do not only reflect the structural characteristics of urban space and the characteristics of how to utilize the spatiotemporal resources, but also show many important topics, including daily activity space of the whole and individual, spatiotemporal utilization restriction, accessibility, and social exclusion. In this sense, this study provides an action direction for implementing the elderly-oriented reform in the community, as well as an empirical basis of typological significance for carrying out simulations and predictions. The contributions it can make are but not limited to:

a) Evaluate the allocation of public resources based on the use;
b) Provide a new measurement method for individual accessibility based on spatial constraints;
c) Change static substantial space planning into dynamic life space planning, and guide the community planning to focus more on the needs of individual residents;
d) Match the schedule and promote the activity arrangement of various public service facilities in the city to help elderlies to choose an appropriate time for medical treatment, fitness, and other activities so that they can receive the greatest service benefits by coordinating the time and resources.

Spatial behavior is the result of choices made by the behavior subject in the built environment. The study on spatiotemporal behavior does not only offer a scientific basis for urban planning and social governance, but also feeds back the knowledge and information to residents. Furthermore, the study provides personalized services for residents and assists senior residents in arranging their daily activities more reasonably. These services include personalized information release service, personal decision-making support services, and behavior guidance.

In terms of releasing personalized information, we can use smart phones to release information on activities, weather, services, and activity suggestions on the premise of grasping the patterns of different behavior of groups and individuals. Providing such information is to make residents' spatiotemporal behavior more efficient, healthy, smart, and environmentally friendly.

In terms of individual decision-making support services, it is recommended to provide residents with multiple activity options under specific spatiotemporal constraints. For example, we can use mobile phone location technology to provide mobile users with value-added services regarding specific information based on their current locations. Besides, we can analyze and predict users' preferences according to historical records of group or individual residents and provide more refined and smart services by combining objective constraints with subjective decision-making factors. Moreover, the spatiotemporal behavior study provides us a foundation to construct individual behavior plans covering short-term schedule, long-term living circle, and long-term life experience.

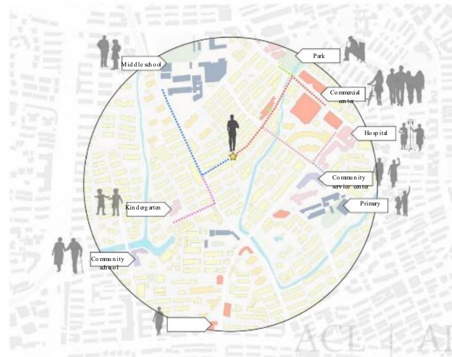


Figure 6-1 Planning of Community Life Circle Based on Characteristics of the Residents

Behavior guidance is to guide residents' behaviors on the basis of information release and decision support services, so as to encourage elderlies to engage in more activities conducive to improving their health. For example, when the support services provide suggestions on personal decision-making, they choose to guide elderlies to engage in activities nearby or at appropriate places by sequence.

6.2 Extended thinking

Traditional planning and decision-makings are mainly done according to existing practical experience that comes from observation of the service objects. However, inevitably, there are fragmentation and subjectivity problems, and the differences between people and personalized choices are often ignored. As for planning and design, refined spatiotemporal data and the cognition of activity patterns through classifying different groups can help planners and designers make correct judgments. The intervention of technological tools will benefit elderlies in the 21st century. It is also an effective way to reduce the expenditure of social resources and ease the burden of family care. Technology also provides a refined matching route for the allocation of space and service resources.

Through collecting spatiotemporal behavior data of elderlies in the built environment and analyzing temporal and spatial characteristics of their daily travel and outdoor activities by age and gender, this study lays a solid data foundation for building an aging-friendly environment. This study provides ideas for improving the community's livability for elderlies through scientific discovery, data analysis, simulation, and prediction. By establishing and accumulating the spatiotemporal behavior database with the community as a unit, we could provide evidence for service allocation decisions based on continuous collection and analysis of the elderly's spatiotemporal behavior in the community. We can also form a flexible mechanism with timely response and expand the effects of simulations and predictions.

This study can be extended to the fields of environmental assessment, health promotion, and other fields. It also plays a positive role in promoting investment in infrastructure for senior care services and fostering the integrated development of senior care service industry. The technological routes, innovative algorithms, and the partial results provided in this study can be applied to the development of smart cities, smart communities, and smart homes if appropriate. The goal of the study is to provide more targeted services for elderlies, improve the space use efficiency and social resources as well as perfect the management model.

In November 2019, the Chinese government issued the *Medium- and Long-term Plan for Responding proactively to Population Aging*, specifying that we should improve the quality of home-based and community senior care, and the technological level of elderly care services. We should shift our development model from labor intensive to technology intensive. We should solve the contradiction of redundancy, shortage, and mismatch between supply and demand. We should meet the development requirements of the new era, and widely use innovative applications. The study carried out in this project with smart phones and fitness wristbands has responded to this development requirement in a timely manner.

One of our new attempts is to discover the research value of the trajectory data based on people's travel. The other is to explore the limitation for carrying out researches based on data subjects. Specifically, data itself does not raise demands, nor provides solutions to problems. The range of data collection and base conditions of the spatial environment need to be clearly defined before the study. Data analysis, the presentation of analysis results, and the application of results require professional knowledge and interpretation ability to complete. GPS data sources bring new opportunities and challenges for interactive analysis between human behavior and the built environment. For example, in order to process massive spatiotemporal data, we should develop new research methods and analytical tools. Another challenge is that we have not developed simple methods to extract effective data from noisy spatiotemporal data.

Meanwhile, we also realized that the increased use of smart devices can convey information, such as health evaluation and activity suggestions, and provide corresponding services; Furthermore, the distance compression and space compression brought by technological progress will greatly influence the daily activities and lifestyles of elderlies. By using the payment, takeout, or medical treatment services on smartphone APP, elderlies can experience the convenience brought by technologies. However, the reduction in travel doesn't necessarily lead to a corresponding increase in leisure travel. The decrease of the needs for staying outdoors and traveling will not only reduce elderlies' physical activities, but also their opportunities for face-to-face communication. The situation faced by empty nesters who feel lonely in their later years may worsen. Therefore, while improving the convenience of life, wearable smart devices should pay special attention to conveying more information that advocate healthy behaviors and active lifestyles, in order to realize the goals of healthy and active aging.

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