1. Introduction

The behavior map is a direct behavior visualization method that observes or records an individual’s behavior (location, activity characteristics, and other information) and links it to various parts of the surrounding environment (Jialin, Yajing, and Dongmei 2018). A behavior map is the product of observations, and also a tool for spatial analysis and design. The behavior map was first proposed by Ittelson et al. (Ittelson 1976) in the late 1960s, and was originally applied to record various behavioral characteristics of people in buildings to help designers connect design features with human behavior in time and space. Subsequently, classic applications such as Jan Gehl’s Public Space and Public Life (PSPL) survey (Jan et al. 2003) and Kevin Lynch’s work in the field of urban imagery (Kevin, Yiping, and Xiaojun 2001) have been widely applied in the field of architecture. The behavior map has five characteristics (Ittelson 1996): ① the plan is clear. ② the behavior of the target individual has the data, description and clear mark in the position. ③ It uses the daily table to record the continuous time. ④ It has scientific program guidance for observation and record. ⑤ It has a system for encoding, marking and counting.

The rise of computers has brought about technological improvements in behavior maps research. The development of big data, cloud computing and geographic information science in the information and communication era has further strengthened the ability to acquire, analyze and apply space-time behavior data. The behavior visualization methods have had considerable development in both the space-time dimension and the application extension depth. In this study, we used CiteSpace and VOSviewer scientific knowledge mapping software to reveal the hotspots, development trends, and field dynamics of space-time behavior maps research in the collected documents. We find that the current research literature on space-time behavior maps shows three areas of clustering: post-occupancy evaluation, public open space, and time geography. By establishing the typical application cases in the three fields, the applications and development frontiers are summarized and considered.

2. Overview of behavior maps research

2.1. The two types of behavior maps

As the earliest used behavior visualization research method, behavior maps can be divided into two categories according to the research objects and application purpose, namely, “person-centered” and “specific environment-centered” (Klein et al. 2018). In this paper, we consider two types of behavior visualization analysis: “person-centered” and “space-centered”.

2.1.1. Person-centered

“Person-centered” behavior visualization analysis mainly focuses on or tracks the behavioral activities of specific individuals. Researchers generally need to obtain the written consent of the research subjects to conduct long-term observational studies, so this
method is time-consuming and labor-intensive. By tracking individual behavioral paths, we can obtain information about their habits, personality, and behavioral characteristics, usually in the form of a chart. For example, Blennerhassett et al. (Blennerhassett et al. 2018) observed the behavior of the elderly occupants of a nursing home throughout the day, and evaluated the most suitable space for the rehabilitation of the elderly in nursing homes. When studying different scenarios, the complexity of the behavior can vary according to the research object. It is also possible to integrate multiple analysis methods, such as questionnaires, interviews, etc.

2.1.2. Space-centered
This type of behavior visualization analysis is designed to observe or document the behavioral patterns of people in a particular environment or space and to analyze the types of activities that occur during a certain time period. This method is often used by landscape architects and urban designers, and is primarily used to study public open space. When Jan Gehl (1965) (Jan and Renke 2002) studied the behavioral characteristics of people on the Piazza del Popolo in Italy, he used space-centered behavior visualization analysis. Through the space-centered behavior map, he found that people tended to stand on the edge of the square space, such as the pillars of the arch, or under the arch or along the facade of the building. This behavior was later described as a “boundary effect”. Similarly, when Goličnik (Goličnik 2005) studied Bristo Square in Edinburgh, he took into account the behavioral conflicts between skateboarders and visitors to the square. In order to better serve these two groups of people, the behavior map method was used to record the behavioral characteristics of the skateboarders and visitors, so that a reasonable area of public facilities could be designed.

2.2. Visual representations of a behavior map

2.2.1. Graphical
The graphical chart (Table 1) was first introduced in the design of the Psychiatric Rehabilitation Institute (by Ittelson et al.) (Ittelson 1970), to express the behavioral characteristics and laws of the subjects studied, and has been subsequently applied to study the relationship between student activities and open spaces (Beeken and Janzen 1978), the evaluation of the use of special care spaces (Bell and Smith 1997), the impact of open spaces on children’s health (Nilda, Robin, and Mohammed 2010), the exploration of the activities of patients during rehabilitation in the built environment (Blennerhassett et al. 2018), the impact of the operating room layout on care workers (Bayramzadeh et al. 2018), and the study of the characteristics of the life habits of Japanese individuals and families over the course 1 day, 1 month, and 1 year (Ellegård et al. 2019).

2.2.2. Symbol code + floor plan
(Barker, 1980) proposed that some basic conditions must be fulfilled before any behavioral activity can be recorded. For example, an accurate scale map of the observation area, the type of observation activity definition, a coding system rule, and the repeated observations planned for a specific time. This was the earliest behavior map representation using symbolic coding plus floor planning (Table 1). This approach has subsequently been applied in the study of urban plaza spaces (Golicnik 2005; Gharib and Salama 2014; Ngesan and Zubir 2015), kindergarten outdoor spaces (Fernandes and Elali 2008; Raymundo, Kuhnen, and Soares 2010; Smith et al. 2014), and urban street spaces (Elsheshtawy 2013). This approach focuses more on the human activities taking place in a specific environment.

2.2.3. Three-dimensional spatial structure slice
(Yanwei 2014) used three-dimensional spatial structure visualization (Table 1) to describe the individual space-time trajectory. The X- and Y-coordinates of the spatial entity represent the spatial plane, and the third attribute of the point data is used to represent the event information; that is to say, the time is represented by the Z-coordinate. The activities of the same individual occurring at different times are connected in series to form a continuous overall individual behavior path.

---

Table 1. Examples of visual representation of a behavior map.

| Graphical | Symbol code + floor plan | Three-dimensional spatial structure slice |
|-----------|--------------------------|--------------------------------------|

---

Example graph, floor plan, and spatial structure slice images.
characteristic. Three-dimensional graphs can more intuitively express the trinity of people, time and space. In describing the events occurring in a scene, it is necessary to consider the change of the flow activity before, during and after the event (Luliliang et al. 2019). The three-dimensional expression of the spatial structure slice can display the relationship between before and after the event in a graph. It can accurately express the changes in people’s time and space.

2.3. Behavior maps method evolution

Behavior maps are visual representations of behavioral data and the related information of graphical representations (Zube and Moore 2013). In 1948, the American psychologist E.C. Tolman first proposed a “cognitive map” in his “Cognitive maps in rats and men” paper, which explained how both animals and humans form a model similar to a live map in their mind, and obtain a comprehensive representation of the environment through their perceptual experience. In 1960, the famous American urban planner Kevin Lynch proposed the five elements of marker, node, region, border, and road that constitute cognitive maps in his book “The Image of the City” (Kevin, Yiping, and Xiaojun 2001). In 1970, Bill Hillier, Professor of the Bartlett School of Architecture at the University College of London, proposed space syntax theory, which studies the behavioral factors in the non spontaneouly formed space and indirectly represents the spatial information such as visibility and accessibility (Bill, Chris, and Fang 2005). At the same time, William H. Ittelson of the University of Arizona presented the “Behavior Map Method” for the first time in the field of visualization of behavioral features to assist in architectural design and space research (Ittelson 1976). In recent years, with the development of digital information technology and big data applications, massive data acquisition methods and various types of visual analysis tools have emerged. Behavior map research has once again reached a climax. In 2013, Anastasia Petrenko of the Department of Geography and Planning at the University of Saskatchewan, Canada, used sensors and WiFi-based positioning systems to track and analyze pedestrian trajectories, enabling visualization of the behavioral trajectories (Petrenko et al. 2013). In 2016, Huang Weixin at the Department of Building Technology Science of Tsinghua University, China, also realized dynamic real-time data visualization based on a WiFi positioning system (Weixin 2016).

Over times, behavioral information categories and data collection methods have undergone a series of changes, and the corresponding behavioral visualization data and tools are constantly changing and progressing. In chronological order (Figure 1), ① Environment-based: the area is swept quickly, all actions are marked on the map and recorded once every time. This can be used to determine the use of each area in the space. ② Chart-based: When the environmental characteristics are not the main focus, the time data are mainly used to calculate the behavior on the chart. ③ Traces-based: observing the traces after the activity to record the behavior occurring in the area. ④ CARS, SOPLAY, SOPARC, and OSRAC-P: Four visualization models in behavioral research, which are mainly used to study children’s activities. ⑤ GPS/GIS/RFID/WLAN: four modern digital information technologies that can track pedestrian walking and cycling behavior track. ⑥ Time-lapse video technology: used to record the behavior data of vehicles or pedestrians using a space for a long period of time.

3. Research focus and frontier trend analysis of space-time behavior maps

In our study, the China National Knowledge Infrastructure (CNKI) database and the Web of Science (WOS) Core Collection database were used as the main data sources, and keywords related to “behavior map” were selected (the search time was up to 31 August 2019). The journal literature, Ph.D. and Master’s paper, and related conference papers about behavior maps published between 1981 and 2019 were obtained. The results were then identified, screened, and corrected. Finally, a total of 916 records were obtained (538 articles from CNKI and 378 from WOS) as the data source of this review. CiteSpace software was used to map the scientific knowledge maps of space-time behavior maps from 1981 to 2019. It was also used to analyze the source countries, keywords, and citations of the relevant research literature, and to summarize the research overview and hotspots of space-time behavior maps. We used the cluster

![Figure 1. Development timeline of behavior maps methods.](image-url)
analysis function of VOSviewer to reveal the frontier trends and field dynamics of space-time behavior map research.

3.1. Research focus

By combining all the collected literature data, we could explore the temporal and spatial characteristics of space-time behavior maps research. From the perspective of the temporal distribution characteristics, the number of papers published on space-time behavior maps has shown an increasing trend, year by year (Figure 2), which indicates that the research on space-time behavior maps has gradually increased in recent years. Before 2009, the number of papers per year remained below 25. After 2010, there was an obvious research boom. The number of publications related to the research increased year by year, and it broke through 100 articles for the first time in 2017. From the perspective of the spatial distribution characteristics, the countries and regions involved in space-time behavior maps research are mainly the United States, Japan, China, and some European countries. Taking 2 years as a time slice and taking the country as a node, the national time slice map of the space-time behavior map research was drawn (see Figure 3). It can be found that the United States has the largest number of publications and the highest centrality (0.33), indicating that its research has high academic value. China’s publication volume is second only to the United States, but its centrality is only 0.08, which shows that China has more room for research and development in the field of space-time behavior map research.
3.2. Research hotspots

The scientific issues explored in a group of papers with relatively large numbers and intrinsic correlations can be seen as a hot topic of academic research during this period of time (Chen 2004). Abstracts and keywords are the refined expressions of the subject and content of the article, and their relevance can reflect the research hotspots in this research field, to a certain extent. The CiteSpace software was used to produce scientific knowledge maps of the collected literature data, which can basically show the research hotspots in this field.

3.2.1. Non-Chinese research hotspots

Only 378 non-Chinese documents were retrieved through the WOS Core Collection database. In order to obtain more comprehensive information on the research into space-time behavior maps in non-Chinese countries, when using CiteSpace to conduct the co-occurrence analysis of research topics, the keywords in the non-Chinese literature and the noun keywords in the abstracts were selected as network nodes for the visualization, from which we can see that the hot topic keywords in the field of non-Chinese space-time behavior maps research are (Figure 4): “time geography”, “post-occupancy evaluation”, “public open space”, “GIS”, “physical activity”, “walking”, “big data”, “global positioning system”, and “social network”. At the same time, using the timeline view analysis function in CiteSpace, the co-occurrence timeline evolution map of the topics studied with regard to non-Chinese space-time behavior maps was drawn (see Figure 5), from which it can be found that research on “time geography” was a hot topic after 1994. For example, the

![Figure 4. Keyword co-occurrence relationship map of the non-Chinese space-time behavior maps research.](image1)

![Figure 5. Keyword co-occurrence timeline evolution map of the non-Chinese space-time behavior maps research.](image2)
application of the time geography time-space prism concept to geographic accessibility (Miller 1991), the measurement of quantitative accessibility (Handy and Niemeier 1997), improved traditional accessibility based on point data and space-time path analysis research (Kwan 1998), a more detailed study of temporal and spatial behavior and accessibility from a female perspective (Kwan 1999b, 1999a), and a conceptual view of time and space from the perspective of physical geography and human geography (Massey 1999). Research on “post-occupancy evaluation” became a hotspot after 2004, such as the use of post-occupancy assessments to study the quality of public housing (Liu 2003), exploring the similarities and differences between post-use assessments and on-site research methods for building thermal comfort (Nicol and Roaf 2005), and post-occupancy assessment studies of residential spaces using radio frequency identification (RFID) technology (Gillott et al. 2006). After 2007, “GIS” and “public open space” became hot topics, in studies such as exploring potential human activities and individual activity interactions in physical and virtual spaces through space-time GIS methods (Shaw and Yu 2007, 2008) and exploring individual large-scale space-time data. Other publications covered space-time GIS visualization methods (Shaw, Yu, and Bombom 2008), an assessment of the bio-climate comfort of the public open spaces in Lisbon (Oliveira and Andrade 2007), the relationship between urban park space design and use (Goličnik and Ward Thompson 2010), the study of racially mixed community public space leisure activities, the exploration of the extent of inter-ethnic interaction (Peters 2010), and the use of behavior maps and GIS techniques to study public open space behavioral occupancy patterns (Marušić 2011).

3.2.2. Chinese research hotspots

The number of related documents collected through the CNKI database was 538. However, the database export literature lacks cited information, and only the keywords of the existing 538 documents could be used as a network node for the co-citation analysis. Since keywords or topics such as “behavior map”, “behavior data visualization”, “space-time behavior map” and “space-time behavior visualization” were searched for, after eliminating these keywords, hot topical themes in the field of Chinese behavior maps research were (Figure 6): “post-occupancy evaluation” “time geography” “public open space” “GIS” “big data” “landscape architecture” “time and space path” “time and space information”, and “environmental behavior”. At the same time, the co-occurrence timeline evolution map of Chinese space-time behavior maps research was also drawn (Figure 7). It was found that research on “time geography” was hot after 2000, in studies such as the introduction of time geography origins, basic concepts, methods, and applications (Yanwei and Enzhuo 1997; Yanwei 1998) and an overview of the application of time geography and possible future applications (Yanwei et al. 2000a; Yanwei and Hua 2000b). After 2004, the research on “post-occupancy evaluation” became a hotspot, in studies such as the introduction of post-occupancy evaluation research in the development of residential theory (Shuxian and Chaohui 2004), the introduction of the post-occupancy evaluation concept, history, method, basic operation mode, and future application prospects (Jing and Shaoxue 2005), and the development characteristics of post-occupancy evaluation in foreign countries and its applicability in China (Donghan 2006). After 2007, “public open space” and “GIS” became hotspots. For example, post-occupancy

![Figure 6. Keyword co-occurrence relationship map of Chinese space-time behavior maps research.](image-url)
evaluation research on established environment and urban public open space (Jianhua 2007), research on the evaluation index system of urban public open space quality and application (Ning et al. 2008), the use of the survey data of daily activities of urban residents in Beijing in 2007 to test data models and methods through GIS tools (Yanwei et al. 2009), the exploration of the application of GIS-based geographic computing and 3D geographic visualization methods in time geography (Kwan et al. 2010), research on the application of GIS-based geographic narrative methods in space-time behavior (Kwan et al. 2013), and research on space-time GIS methods and summarizing the quantitative analysis of human behavior problems (Shaw and Zhixiang 2014; Shaw, Jie, and Feng 2016).

3.3. Frontier trends

By introducing the collected 916 records into the VOSviewer for overlay visualization analysis, the frontier theme and trend relationship map of space-time behavior map research were obtained (Figure 8), from which we can find that “public health”, “daily activities”, “living space”, “elderly”, “big data”, “quantitative analysis”, “smart city”, “data mining”, and “text mining” are the most cutting-edge topics in the study of space-time behavior maps since 2016. At the same time, it can be seen that the derivative development trends surrounding the research hotspot of “time geography” are “GIS”, “time and space information”, “information visualization”, and “time and space trajectory data”.

4. Behavior maps research application and case analysis

Three core clustering views of space-time behavior map research were obtained by the cluster analysis of VOSviewer. This also revealed three dynamic clusters of space-time behavior maps research. Among them (Figure 9), red represents the post-occupancy evaluation research field, green represents the public open space research field, and blue represents the time geography research field. The following is a brief overview of the dynamics of the three major areas, in order to introduce and summarize the typical application cases in various fields.

4.1. Post-occupancy evaluation applications

The high-frequency keywords in this field are “architecture”, “Physical Activity”, “User Behavior”, “Indoor Positioning System”, “Global Positioning System”, “Indicator System”, “Indoor Environment Quality”, and “GPS data” (Figure 9, red area). The dynamics of this field are mainly focused on the use of new post-occupancy evaluation new methods based on behavioral data visualization, in addition to the basic methods of post-occupancy evaluation. The following are three related research applications:

Case 1: (Gillott et al. 2006) conducted a post-occupancy evaluation based on the relationship between the use of new residential space in the UK and the changing lifestyle needs of consumers. The RFID tracking system was used in the evaluation to collect the occupancy data of each space in the house by tracking the RFID reader and wristband tags worn by each family member. Overall, the project was very successful, providing information for developers on flexible open spaces for small homes, as well as the recent market trends.

Case 2: (Petrenko et al. 2013). GPS cannot accurately obtain the location of indoor personnel positioning, so this case study used an indoor WiFi positioning system and multi-sensor smartphone platform, with the assistance of 37 volunteers. After a one-month experiment, this study successfully tracked and collected more than 36 million pedestrian indoor trajectories, and realized
the visualization of the behavior trajectories by centrally processing and analyzing the behavioral big data (Figures 10 and 11). The results not only revealed the relationship between individual spatial behavior and decision-making, but also helped to significantly improve building management, emergency operations, and security controls. Case 3: (Weixin and Lijing 2018) took a pair of retired couples as an example, using ultra-wideband (UWB) technology to conduct a three-week study on the indoor living behavior of the users, and finally refined and quantitatively analyzed the residential behavior data (Figure 12). The daily activities of family members and the changes in their behavioral timing were obtained, and the ratios of the time spent by family members in various functional spaces were counted. This precise indoor positioning technology not only revealed some neglected residential behavior patterns and potential residential needs, but also provided an early basis for the design of residential spaces; it also provided some quantitative data support for future architectural design.

4.2. Public open space applications

The high-frequency keywords in this field are “public health”, “walking”, “visualization”, “environmental behavior”, “child”, “elderly”, “spatial behavior pattern”, and “time and space trajectory data” (Figure 9, green area). The research in this field mainly investigates the relationship between public open spaces and healthy living, walking, and the use of population characteristics. The following are three related research applications:

Case 1: (Lestan, Eržen, and Golobič 2014) studied the relationships between public open space quality and healthy lifestyles in residential development projects in Ljubljana, Slovenia, from the perspective of vulnerable groups such as the elderly and children. The study, through behavior mapping and resident opinion surveys, confirmed the differences in open spaces in selected residential areas and their relationship with outdoor activities, and also revealed a range of socioeconomic variables (such as education and economic conditions) for people’s physical activity and the strong influence on the perceived health status.

Case 2: The Environmental Behavior and Space Design (EBSD) research group (Xia, Haoran, and Chang 2018) took the open space of the Sakura Mountain Top area of Wuhan University as the research object, and analyzed the influence of the behavior pattern of both tourist and students in the space. A smartphone trajectory recording app was used to track the tourists and
Figure 9. Topic keyword VOSviewer clustering analysis map of space-time behavior maps research.

Figure 10. Aggregate trajectories drawn by participants in the Petreno et al. (Petreno et al. 2013) study; darker areas correspond to indoor campus paths (emphasis added).

Figure 11. (a) 2D view of the trajectories recorded in the Petreno et al. (Petreno et al. 2013) study; (b) 3D view of the trajectories, with the arrows corresponding to the directions of travel.
students in this space, combined with photographs and on-site questionnaires. Finally, based on a GIS platform, the data were analyzed and processed from three aspects: route interference, line-of-sight interference, and domain interference (Figure 13). Conclusions were then made based on the optimization of the landscape space for students and tourists, and a recommendation for the best view point in the space was made (Figure 14).

Case 3: The EBSD research group also conducted research on the Wuhan University campus public space security map and the campus boundary space open strategy. In the initial study, five operability indicators (space visibility, functional mixture, space environment, space accessibility, and space vitality) were selected from the various influencing factors for public space security. Based on the GIS platform, a public space security map of the campus (day and night) was drawn (Figure 15), and then the trajectory recording app was used to collect and analyze the behavior trajectories of teachers and students on the campus, supplemented by questionnaire survey to verify the rationality of the security map. In the later research, GPS trajectory data, OpenStreetMap road data, and point of interest (POI) facility data were collected. The behavior trajectory analysis and origin-destination (OD) cost matrix analysis method were used to analyze the open status, use status, and open demand of campus boundary space. The analysis, supplemented by questionnaires and field research, selected the boundary with open conditions to propose a spatial optimization strategy.

Case 4: (Jing 2018) took the historical protection area of 1.76 km² in AnDingmen Street of Beijing as the research object, and established the spatial indicators of the behavior of the elderly, according to the three factors of sunshine, green space, and humanities, and the established medical, entertainment, catering, and shopping facilities. A physical space evaluation system was developed at the level of transportation, financial services, and education. Through the GIS platform used to track the activities of the elderly and identify the street view images, 741 scenes were finally visualized (Figure 16), and the physical space attribute information was obtained. Principal component analysis and regression analysis were then used to obtain the main impact of the physical space of the elderly. This explained how these factors affect the behavioral space mechanism.

Figure 12. (a) Schematic diagram of house layout and equipment installation recorded in the Weixin and Lijing (Weixin and Lijing 2018) study; (b) one-day male owner activity space distribution heat map; (c) One-day host activity space distribution heat map.

Figure 13. The EBSD study (Xia, Haoran, and Chang 2018) of the Sakura Mountain Top area of Wuhan University: (a) line of sight interference trajectory line distribution; (b) line interference trajectory line distribution; (c) field interference trajectory line distribution.
4.3. **Time geography applications**

The high-frequency keywords in this field are “GIS”, “big data”, “space-time prism”, “time and space information”, “time and space path”, “data visualization”, “data mining”, and “smart city” (Figure 9, blue area). The field dynamics mainly focus on the application of 3D information visualization methods in time geography and the related research based on space-time behavior data visualization analysis.
Case 1: (Kwan 2005) studied 216 (100 male, 116 female) residents with driver’s license with an average age of 42.6 from 100 families by a GPS mobile data collection test in the Lexington area of the United States. The information was collected for each respondent on a Saturday trip, totaling 2,758 travel records and 794,861 data points with latitude and longitude and time information. The GIS-based 3D visualization function then generated a 3D space-time path map of a female sample without children under 16 years old (Figure 17), revealing that the travel was mainly along highways and main roads, showing that the 3D visualization can reveal different space-time behavior patterns.

Case 2: The EBSD research group (Xia et al. 2016) used 28 road landscapes in Wuhan as the experimental object. Through the collection and analysis of network heat data such as road landscape search volume, signs and social media likes, a comprehensive road landscape evaluation model was established. The landscape view field was also combined to obtain the road “beauty degree”. In addition, the “most beautiful path optimization algorithm” was designed and implemented based on the distance and time constraints, and the most beautiful path algorithm was compared with the traditional shortest path algorithm. The results shown that in the same situation of start and end points, the most beautiful path algorithm could find a more beautiful path within the distance (time) threshold constraint, and could thus improve the pleasure in the travel process.

Case 3: (Luliang et al. 2019), took the 2015 Jay Chou World Tour Concert (Wuhan Station) as an example of a major urban event, and proposed a city event space-time model analysis method that combines real-world traffic data with social media data. The GPS trajectory data of offline taxis in Wuhan and online microblog data were adopted to realize a full-time modeling analysis of the urban geospatial space and behavior space in the pre-, and post-stages of the concert (Figure 18). The results shown that the method is effective and innovative in analyzing the spatial and temporal evolution process of an urban activity event.

5. Discussion and conclusion

5.1. Discussion

Combining the development of the space-time behavior maps research with the existing research and application results, it shows the following development trends:

First, the advent of the era of big data and the continuous development of information and communication technology (ICT) have prompted the space-time behavior maps research to show the trend of multi-source research data, diversification of research means, individualization of research objects and specific of research topics, which will make the application of behavior maps to unprecedented levels.

Second, behavior maps have broken through the limits of qualitative analysis and the simple application of traditional data in the development of multidisciplinary integration. This will allow us to reveal the spatial and temporal relationships between individuals and social life through multidimensional dynamic displays of space-time behavior data, and will allow us to explore the temporal and spatial patterns of people’s behavior patterns hidden behind the data.

Finally, in the practical application of behavior maps, “People-oriented” conception will be valued. The space-time behavior maps’ visual expression of individual behaviors makes it a medium for people-oriented conception to be more specifically placed in

Figure 17. Space-time paths based on GPS data from the Lexington area of the United States (Kwan 2005).
the practice of urban planning and architectural design. It also enables space-time behavior research, space planning and design, built environment with reconstructed, use and post-occupancy evaluation form a benign working cycle together. Based on the benign working cycle, it will improve the quality of human settlement environment.

5.2. Conclusion

In this paper, the concept and types of behavior maps have been first briefly summarized. The development and evolution of behavior maps research methods has also been described. Based on the CNKI database and the WOS Core Collection database, CiteSpace and VOSviewer software were used to visualize the hotspots and the frontier trends of space-time behavior maps research. Three dynamic clusters of space-time behavior maps research were revealed by cluster analysis.

The main contributions of this study can be summarized as follows:

First, behavior maps were initially used as a direct and observational behavior visualization research method. According to the research objects and application purposes, behavior maps can be divided into “person-centered” and “space-centered”. These two types of behavior visualization analysis basically summarize the research and application of behavior maps.

Second, the rise of computers, the change of technical means and the loading of information and data have made the visual representation of behavior maps from the initial simple two-dimensional graphical chart representation to the use of complex symbol code + floor plan representation, and finally towards the three-dimensional expression of space-time structure. At the same time, the diversity of information data categories and the advancement of data acquisition tools have promoted the evolution of behavior maps method. From environment-based, chart-based to model-based and video-based technologies, behavior visualization methods have had considerable development in both the space-time dimension and the application extension depth.

Third, through comparative analysis, on the one hand, there is an upward trend in space-time behavior maps research; on the other hand, compared with the study of non-Chinese behavior maps in the time dimension around 1994, Chinese research was lagging, but it is currently in a research boom. At the same time, the hotspot evolution process of space-time behavior maps is basically the same, which is divided into three stages, that is, the study stage of space-time behavior from the perspective of time geography, POE (post-occupancy evaluation) study stage and public open space study stage. In the study stage of time geography, GIS, spatiotemporal trajectory data and spatiotemporal information visualization are becoming the latest research hotspots in space-time behavior maps in China.

Fourth, the research and application of the existing space-time behavior maps has mainly focused on the fields of post-occupancy evaluation of buildings, public open space, and time geography. In general, behavior maps have more research results in geography and urban scale of time geography, and in architectural scale of post-occupancy evaluation; while research into urban mesoscale of public open space has greater potential for application.

Disclosure statement

No potential conflict of interest was reported by the authors.
Funding

This work was funded by the National Natural Science Foundation of China [Grant No. 41671442]; Human Behavior Patterns Analysis and Space Optimization based on the Big Trace Space-time Data.

References

Barker, R. G. 1980. “Ecological Psychology - Concepts and Methods for Studying the Environment of Human-behavior.” Social Behavioral Science 10.

Bayramzadeh, S., A. Joseph, D. San, A. Khoshkhekar, K. Taaffe, R. Jafarifiroozabadi, and D. M. Neyens. 2018. “The Impact of Operating Room Layout on Circulating Nurse’s Work Patterns and Flow Disruptions: A Behavioral Mapping Study.” HERD: Health Environments Research & Design Journal 11. doi:10.1177/1937586717751124.

Beeken, D., and H. L. Janzen. 1978. “Behavioral Mapping of Student Activity in Open-Area and Traditional Schools.” American Educational Research Journal 15 (4): 507–517. doi:10.3102/002201200150040507.

Bell, P. A., and J. M. Smith. 1997. “A Behavior Mapping Method for Assessing Efficacy of Change on Special Care Units.” American Journal of Alzheimer’s Disease 12 (4): 184–189. doi:10.1177/153317597012004017.

Bill, H., S. Chris, and H. Fang. 2005. “A New Approach to Spatial Syntax.” World Architecture 46–47. doi:10.16414/j.wa.2005.11.008.

Blennnerhassett, J. M., K. N. Borschmann, R. A. Lipson-Smith, and J. Bernhardt. 2018. “Behavioral Mapping of Patient Activity to Explore the Built Environment during Rehabilitation.” HERD: Health Environments Research & Design Journal 11. doi:10.1177/1937586718785444.

Chen, C. 2004. “Searching for Intellectual Turning Points: Progressive Knowledge Domain Visualization.” Proceedings of the National Academy of Sciences U.S.A. (Supplement 1): 5303–5310. doi:10.1073/pnas.0307513100.

Donghan, Z. 2006. “Evaluation of the Development Characteristics of POE in Foreign Countries and Its Applicability in China after Use.” Acta Scientiarum Naturalium Universitatis Pekinensis 797–802. doi:10.13209/j.0479-8023.2007.127.

Ellegård, K., U. Linköpings, T. O. Teoma, F. Filosofiska, and F. T. Institutionen. 2019. Thinking Time Geography: Concepts, Methods and Applications. Abingdon: Routledge.

Elsheshawy, Y. 2013. “Where the Sidewalk Ends: Informal Street Corner Encounters in Dubai.” Cities 31: 382–393. doi:10.1016/j.cities.2012.12.001.

Fernandes, O. S., and G. A. Elali. 2008. “Reflections on Child Behavior in a Schoolyard: What We Learned from Observing Children’s Activities.” Paidéia (Ribeirão Preto) 18 (39): 41–52. doi:10.1590/S0103-863X2008000100005.

Gharib, R. Y., and A. M. Salama. 2014. “Nature of Urban Interventions in Changing the Old Center of Globalizing Doha.” Frontiers of Architectural Research 468–476. doi:10.1016/j.foar.2014.06.004.

Gillott, M., R. Holland, S. Riffat, and J. Fitchett. 2006. “A Post-Occupancy Evaluation of Space Use in a Dwelling Using RFID Tracking.” Architectural Engineering and Design Management 2: 273–288.

Golicnik, B. 2005. “Public Urban Open Spaces and Patterns of Users.” In 18th Conference of the International Association-for-People-Environmental-Studies, Vienna, Austria, July 7–10, 2004. Toronto, Canada: Hogrefe & Huber Publishers.

Goličnik, B., and C. Ward Thompson. 2010. “Emerging Relationships between Design and Use of Urban Park Spaces.” Landscape and Urban Planning 94 (1): 38–53. doi:10.1016/j.landurbplan.2009.07.016.

Handy, S. L. N., and D. A. Niemeier. 1997. “Measuring Accessibility: An Exploration of Issues and Alternatives.” Environment and Planning A: Economy and Space 29 (7): 1175–1194. doi:10.1068/a291175.

Ittelson, W. H. 1970. “Some Perceptual Differences in Somatizing and Nonsomatizing Neuropsychiatric Patients.” Psychosomatic Medicine 23. doi:10.1097/00006842-196105000-00003.

Ittelson, W. H. 1976. “Behavioural Science and the Rationalisation of Architectural Design.” World Hospitals 12 (1): 59–62.

Ittelson, W. H. 1996. “Visual Perception of Markings.” Psychonomic Bulletin & Review 3. doi:10.3758/BF03212416.

Jan, G., G. Lars, T. Yuyang, W. Bing, and Q. Jun. 2003. Public Space—Public Life. Beijing: China Building Industry Press.

Jan, G., and H. Renke. 2002. Communication and Space. Beijing: China Building Industry Press.

Jialin, Z., L. Yajing, and L. Dongmei. 2018. “Application of Behavior Map in the Study of the Relationship between Kindergarten Outdoor Activities and Children’s Physical Activities.” China Sport Science and Technology 54: 91–97 +104.

Jianhua, C. 2007. “Urban Open Space and Post-Evaluation of Environmental Use.” Archives Des Sciences 102–105. doi:10.13614/j.cnki .11 -1962/tu.2007.09.026.

Jing, G. 2018. The Match of Physical Space and Behavioral Space among the Elderly of the Old City in New Data Environment:A Case Study of Andingen Sub-District. Wuhan, Hubei, China: Publisher.

Jing, H., and H. Shaoxue. 2005. “A New Introduction to the Theory of Post-Occupancy Evaluation (POE).” Architectural of Journal 80–82.

Kevin, L., F. Yiping, and H. Xiaojun. 2001. Urban Imagery. Beijing: Huaxia Publishing House.

Klein, C., A. Kuhnlen, M. L. Felippe, and B. B. Silveira. 2018. “Place-Centered or Person-Centered? Considerations about the Behavioral Mapping Approach.” Trends in Psychology 26: 593–616.

Kwan, M. P. 1998. “Space-Time and Integral Measures of Individual Accessibility: A Comparative Analysis Using A Point-based Framework.” Geographical Analysis 30 (3): 191–216. doi:10.1111/j.1538-4632.1998.tb00396.x.

Kwan, M. P. 1999a. “Gender and Individual Access to Urban Opportunities: A Study Using Space-Time Measures.” The Professional Geographer 51 (2): 211–227. doi:10.1111/0033-0124.00158.

Kwan, M. P. 2005. “GIS Methods in Time-Geographic Research: Geocomputation and Geovisualization of Human Activity Patterns.” Geografiska Annaler: Series B, Human Geography 86: 267–280.

Kwan, M. P., G. Zhillian, T. Na, and C. Yanwei. 2013. “Application of Qualitative GIS in Time and Space Behavior Research.” Progress in Human Geography 32: 1316–1331.

Kwan, M. P., S. Yue, Z. Ying, and C. Yanwei. 2010. “GIS Method in Time Geography Research: Geographical Calculation and Geographical Visualization of Human Behavior Models.” International Urban Planning 25: 18–26.

Kwan, M.-P. 1999b. “Gender, the Home-Work Link, and Space-Time Patterns of Nonemployment Activities.” Economic Geography 75 (4): 370–394. doi:10.2307/144477.

Lestan, K. A., J. Erzen, and M. Golobić. 2014. “The Role of Open Space in Urban Neighbourhoods for Health-Related
