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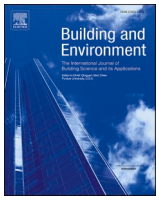

Behaviour in public open spaces: A systematic review of studies with quantitative research methods

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ABSTRACT

Public open spaces are important assets that play a significant role in city lives, based on which a great number of behaviour-based studies are being conducted. These studies often use one or more case studies to observe people's preferences and usage habits and to investigate their influencing factors such as outdoor thermal comfort, environmental conditions, urban configuration, and local settings.

Because the subject is complex and falls within the purview of multiple academic disciplines, it is a challenging task to understand the current status and development trends of existing studies. To fill this gap, this article presents a systematic review of quantitative evidence-based behaviour studies in public open spaces. Following the PRISMA method and searching using eight academic search engines, full texts of 116 research articles have been included for this review.

The main contributions of this review are that: (1) it proposed a relatively complete system that categorizes people's behaviour in public open spaces; (2) it introduced outdoor subjective influencing procedure including behaviour, feeling and health impacts; (3) the review illustrated the distribution of existing research as well as research trends; and finally (4) the article also timely discussed the influence of the COVID-19 on people's behaviour in public open spaces.

The authors consider this article to be useful as it can facilitate further behaviour-based studies in public open spaces. With a robust classification and future trend discussion of factors associated, fellow researchers, urban designers, city managers, and policymakers are easier to integrate and use the knowledge learned.

1. Introduction

1.1. Background

Public open spaces, as an interdisciplinary field in urban design, landscape, and outdoor architecture circumstance, is an essential component in urban built environment. Different from private spaces tending to satisfy the needs of individuals. High-quality public open spaces including pedestrian-only streets, squares, parks, playgrounds, and other communal areas, have played an important role in daily lives [1]. As the main component of outdoor-built environment, they have offered opportunities for recreational activities and act as outdoor gym, social occasion, and visual amenities [2–5]. And they could play important role in health urbanism as part of providers of supportive environments [6].

The condition of public open spaces influences people's behaviour, which is the main indicator that reflects people's perceptions, feelings, and needs. There has been a burgeoning number of studies from the

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space users' perspective in the past few decades. Among them, Camillo Sitte [7], William H Whyte [8], Jan Gehl [9,10], Gordon Cullen [11], Edmund N. Bacon [12], and others described the relationships between outdoor behaviour, user's feeling, space image, and other related points. Most of these classic works were based on qualitative studies including interviews, focus groups, case studies, narrative inquiry, storytelling, or observation without numerical analysis. In recent decades, qualitative methods were widely applied to deep-seated behaviour-circumstance interactions. Such as unstructured and semi-structured interviews were conducted to study the space users' preference and well-being in specific places. For example, walk-along interviews have been used to understand the critical factors that influence adolescents' active and social interaction in parks. 34 participants were interviewed and the descriptive statistics from the survey data were calculated using Stata/SE and the audio transcripts were coded and analysed using NVivo software in the study [13]. Another study [14]uses the evaluation program MAXQD to interpret questionnaire results and open-ended questions answers from 113 participants. The results uncover the relationship between blue environments and their benefits for mental well-being. In contrast to the qualitative method's descriptive illustrations, quantitative studies rely on numerical or measurable data, and they often lead to statistical analysis. Quantitative studies can be categorised into two types. Studies involve data acquisition of subjective responses, coding, and frequency query; and studies without subjective influence.

The first type studies often involve data collection through questionnaire surveys, observations, structured interviews and numerical analysis. This type of study can provide informative evidence such as Likert-scale [15] to study behaviour-feeling interactions, space visitation to investigate users' habits [16], or activity distinguishing and user counting to reveal seasonal changes in usage patterns and behaviours on university campuses [17]. The second type of study is purely based on data acquisition from equipment without subjective influence, such as activities tracing through a camera, thermal imaging, wi-fi [18] and accelerometer [19]. They can offer objective observations without direct engagements with participants, and are cable to generate evidence for site occupancy, space users counting, and activity intensity.

In specific, with the wider range of measurement techniques developed in recent years, the number of quantitative studies has started to increase from the year 2000. Among them, several large-scale projects and collaborative studies, including the HABITAT project [20,21] in Australia, the PEACH project [19] in the UK, the RUROS project [22] in Europe, and the IPEN project [23] covering 12 countries internationally, have conducted quantitative studies on people's behaviour in public spaces. Their research objectives were to understand the relationship between outdoor behaviour and thermal comfort optimization, environmental perception investigation, and health promotion through the review of recent quantitative studies. Outdoor behaviour studies based on quantitative research method play a crucial role in enhancing knowledge and enabling the design of comfortable, useable, and healthy spaces.

1.2. State of art

Several review papers have been conducted based on behaviour studies in public open spaces. Multiple associated factors, type of circumstances, and interactions have been focused and highlighted in reviews based on public open spaces. Factors could influence public space usage were separately discussed: influence bring by people's background including gender, age, region, and other factors; context and locations' influence including district density, and different type of circumstances; environmental component including greenery, shading, hardware and facilities; and climate stimuli including seasonal and microclimates' aspects were specified and reviewed separately [24]. In dense urban areas, accessibility and features were considered as two main influencing aspects: accessibility's influence, including distance, presence, percentage, and number of public open spaces; and features of areas including paths and jogging trails; open areas including squares and plazas; natural areas including water features, lawns or groves; sports fields and courts; place near water features; corridors use as rest areas; architecture settings such as pavilions and pergolas; and the usage of fitness equipment, have been systematically reviewed [1]. In pocket parks [25], factors contributing to general usage were reviewed and categorised as personal factors, social factors, physical factors, perceived environments, and other factors. Among these influencing factors, climatic factors, including their thermal comfort association with behaviour, have been studied and highlighted. Based on the focus of thermal sensation and adaption [26], earlier studies of thermal-behaviour interaction were first introduced in detail [27]. Thermal comfort studies and mitigation strategies have been studied in outdoor urban spaces [28,29], and related theories and applied qualitative methods have also been highlighted [30,31].

In addition, attributes of behaviour, specifically physical activity, have been highlighted. Owing to its close link with health [32], physical activity was widely studied as a multidisciplinary approach. Environment attributes are categorised into five types: accessibility of facilities, opportunities for activity, weather, safety, and aesthetic attributes [33]. Five themes including health, social connectedness, affordable, support, and design and promotion have been considered as main points affect outdoor gym usage in public open spaces [5]. Similarly, in the area of social environment, five dimensions, including social support and social networks, socioeconomic position and income inequality, racial discrimination, social cohesion and social capital, and neighbourhood factors were reviewed and introduced separately [34]. To promote physical activity, the usage and arrangement of parks were highlighted from different aspects, including overall usage and activity intensity [35], park and neighbourhood environmental factors [36], and recreational settings [37]. Several confusing points in concepts, methods and research agenda including physical activity mode, types of spaces studied, metrics measures, characteristics of the surrounding, varying associations, identifying thresholds were distinguished and specified [2]. And because of the close link with the health situation [38], green spaces have also been highlighted [39]. In addition to the general influencing factors, walking, as a specific type of physical activity, was classified, separated, and reviewed in detail for different reasons [40]. Furthermore, specific groups, including children [41] and dog owners [42] were also focused on because of their specific characteristics and need for physical activity.

Overall, existing studies on people's outdoor behaviour are complex owing to their diverse objects, circumstances, influencing factors, and research contents. Most outdoor behaviour-related reviews were limited to a single population group, such as the elderly and children. Or they looked at a particular type of physical activity such as walking, sitting, or running. Other types of behaviours have not been studied much and therefore cannot form a complete system. In the field of public open spaces, relationships between types of behaviour and specific circumstances have not been adequately discussed, which has led to a lack of relatively comprehensive and systematic attention based on all types of behaviours.

1.3. Aim and structure of this review

To fill the gap, this article presents a systematic review of quantitative evidence-based behavioural studies on public open spaces. It aims to provide a relatively comprehensive understanding of the research content, categories of behaviours being studied, types of feedbacks associated investigated, as well as research trend and future research directions were proposed.

The remainder of this paper is organised as follows.

The article first introduces the background and importance of the research topic and then explains the research methodology in Section 1 and Section 2.

Section three presents a statistical analysis of existing studies by

reviewing their temporal and geographical distribution. Multiple influencing factors shaping outdoor behaviour, mentioned in existing studies, have been extracted and categorised.

People's outdoor behaviour in urban spaces is categorised in Section four using different classification systems, including specified movement, type of activities with the same attribute, site attendance, and alternative classification systems.

Subjective feedbacks were discussed in Section five. Considering associated with activity in public open spaces, types of feelings and health impacts were frequently investigated in both before and after behaviour stages. Besides this, a subjective influencing procedure was formed. Characters, research content, and factors associated were discussed.

Changes in pandemic are highlighted in Section 6, among which studies conducted after the first outbreak of COVID-19 were analysed, and future research trends are suggested.

The last section includes conclusion, limitation, and future research.

2. Method of review

This study reviews research articles published in English which use quantitative evidence-based methods to understand people's behaviour in public open spaces. The review process follows the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) approach to identify and screen studies related to people's behaviour in public open spaces and conduct further eligibility and inclusion checks as illustrated in Fig. 1. The PRISMA approach was introduced in the late 1980s to summarize the key outcomes from medical journals and to help clinicians keep up to date with their field. This method has become popular in our research field because of its simplicity and thoroughness. The four-stage review process is as follows.

(1) Identification: In the fields of architecture, landscape, urban design, and behaviour study, academic journals are commonly published by Elsevier, Springer, Taylor & Francis, Sage, Wiley and MDPI. Therefore, ScienceDirect, SpringerLink, Taylor & Francis Online, SAGE Journals, Wiley Online Library, and MDPI were chosen as the search engines. To avoid the missing of important documents, Web of Science, PubMed were also implemented to get a more comprehensive searching.

(2) Screening: Using the keywords (outdoor OR public OR "open space") AND (behavior OR behaviour OR behaviors OR behaviours OR activity OR activities). Both American and British spellings are included in the searches and their plural forms have been considered by search engines.

Due to the setup of search engines, different databases were searched using slightly different methods. The title, abstract, and keywords search have been used in Web of Science, and Science direct; The title and keywords search have been used in MDPI; The title and abstract search have been used in PubMed; The keywords search only have been used in Wiley, Sage, and Taylor & Francis Online; and the content search has been used in Springer.

A large number of papers were found. To narrow down the scope, discipline and subdiscipline selection were conducted in Web of Science, Springer, and Science Direct, and papers in unrelated disciplines such as physics, business, and clinical medicine were excluded. Papers published in irrelevant journals such as the journal of radiation protection dosimetry, energy policy et al. were also excluded in Web of Science and Science Direct.

Since a large proportion of irrelevant articles could still be found on Web of Science, Springer, and PubMed in this step, only the top 10,000 relevant search results were included for the next step. After all, a total of 40,405 search results were identified for the initial consideration. Among them, 39,502 papers were excluded in the next step through duplicated papers removed, journal type checked, and the screening review of abstracts, types of articles, and research subjects.

The scope of this review is also limited by the type of space studied. Authors only included urban public open spaces, and excluded public spaces in rural environments, such as national parks, and mountain areas. Because there are much more literatures on macro-scale which are discussing tourism, walkability and active transport, this review is

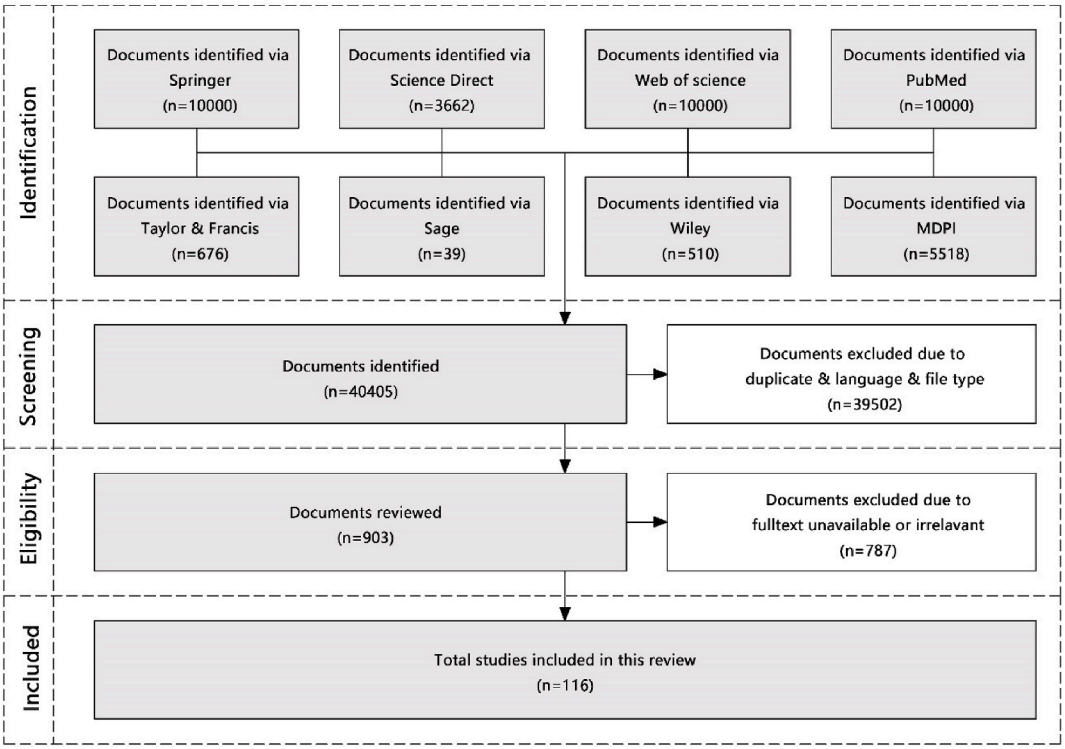

Fig. 1. Method of review.

focusing on micro-scale public open space. In terms of the dimensions of the scale, there is no quantifiable metric, but we have limited the scope to a park, single walkable neighbourhoods, or a square et al. The full text of the remaining 903 articles was included in the next step.

(3) Eligibility check: A further screening process was conducted through full-text eligibility checks. Both types of quantitative studies (explained in the background section) were included for the next step. Articles beyond the scope of this study, such as those using qualitative investigation methods only, were excluded. Articles that focused only on subjective feedback, such as comfort, feelings, and health, and did not investigate human behaviour were also excluded. Studies focusing on the thermal adaption of adding cloth only without consideration of the urban environment were also removed for the next step. Circumstance in city and transport scale or have nothing to do with public open space design and arrangement were excluded. The remaining 116 articles were included in the systematic review.

(4) Inclusion: The review started with statistical analysis based on the keywords, temporal distribution, and geographical distribution of all selected 116 studies. Then, all the selected articles were summarized and analysed in terms of the classification of behaviours, attributes, and site attendance. Alternative classification systems have also been proposed and differentiated. The results are as follows.

3. General introduction of existing studies

3.1. Factors associated with behaviour-based studies

Compared with indoor research in a relatively stable environment, outdoor behaviour is affected by more complex circumstances, influencing factors, and associated with complicated human feedback. To obtain a better understanding of relevant factors. Most frequently and commonly studied factors were extracted from the 116 papers selected. The network analysis of these factors was performed in the open-source Gephi software as shown in Fig. 2.

The size of the character indicates the times that the factors were studied. For example, physical activity (the biggest size) is a well-known factor associated with public outdoor spaces and it has been investigated in many articles. Factors studied in the same article were linked with the lines. The darker and thicker the lines are, the stronger links exist between these factors. For example, physical activity has a strong association with Greenery & greenspace, parks, and neighbourhoods, as illustrated in the darker and thicker lines.

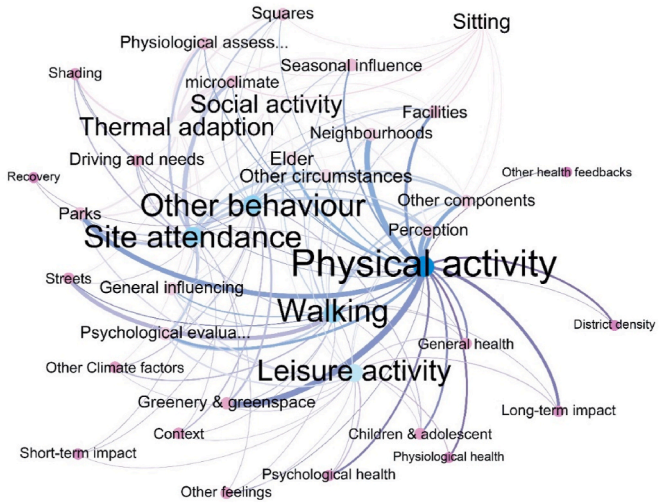

Fig. 2. Main points mentioned in behaviour-based outdoor studies.

Based on the authors' review, these factors were grouped into objective influencing factors and subjective feedbacks. The objective influencing factors include those factors which are not driven by people, such as location-related factors, the density of district, neighbourhood settings, climate, and environmental settings. As shown in Fig. 3, objective influencing factors could be categorised into in-situ factors and background factors. Indirect linking with people's needs, context and location of the outdoor built environment were shown as background information. Subjective feedbacks are the factors associated with people. Among them, feeling and health conditions were most frequently studied subjects in behaviour-related studies.

3.2. Distribution of recent studies

The number of quantitative behavioural studies conducted is shown in Fig. 4. This number has increased significantly over the past 10 years.

Specifically, physical activity made up the largest proportion of the topics studied. Studies focusing on physical activity have been particularly numerous in the past two years owing to the attention it receives in the field of environmental design. Anyhow, physical activity has been studied in other disciplines for a long time. Research related to the overall occurrence of physical activity has also received much attention each year, while other types of behaviour were relatively less studied, due to which they could not form a relatively complete system.

To obtain a better understanding of investigation area distribution, different types of behaviour are labelled with distinguishable colours, as shown in Fig. 5 based on the climate classification [43]. Among them, studies carried out field surveys in multiple regions are labelled in multiple zones correspondingly.

Among them, most of the studies were relatively concentrated in Southeast Asia, the East and West coasts of North America, and Western Europe. Most of these places are well-developed, while relatively few studies were conducted in other regions, making them particularly representative [44].

In terms of the distribution of movement types, investigations in Europe and Asia were more diverse, while studies in America and Oceania focused more on in-depth research on physical activities. Several behaviour-related projects have been conducted in Europe, which contains diverse fields of behaviour investigations and types.

Studies were mainly distributed in temperate and subtropical zones while investigations in more extreme climate environments were fewer. Owing to the different habits and preferences of residents living under different climatic conditions, outdoor activities in diverse climatic zones should be considered.

In general, the number of existing behaviour-based studies is relatively small, and they cannot form a relatively comprehensive system worldwide. In terms of climate zones, discussions on the interaction between climate and behaviour have failed to take the wide range of

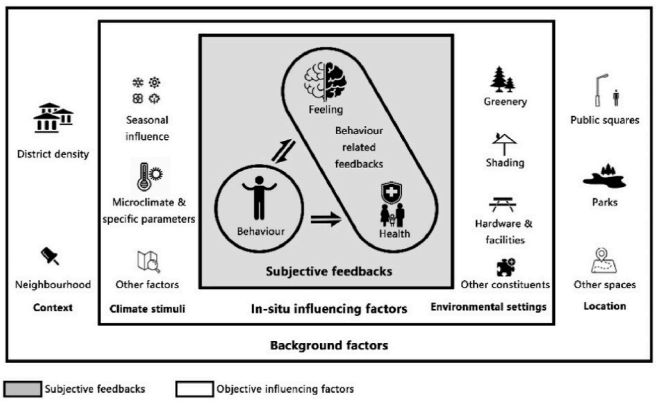

Fig. 3. Behaviour-related factors.

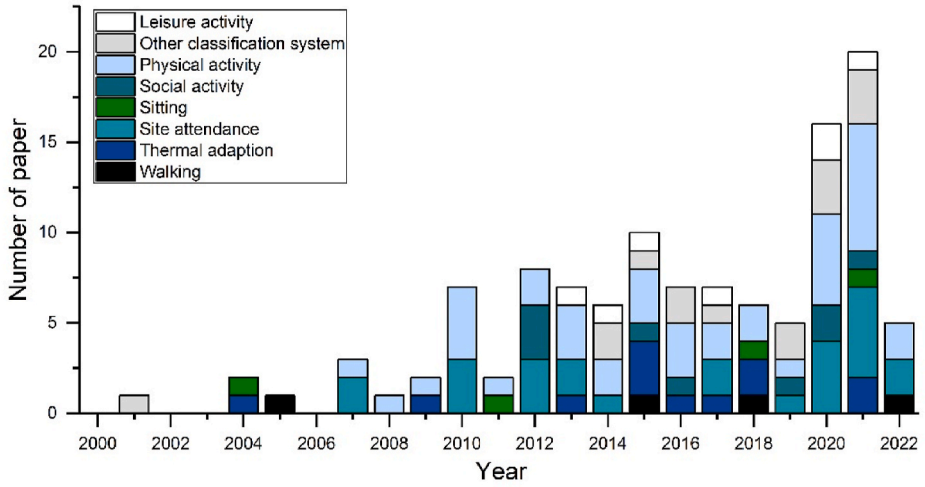

Fig. 4. Records of recent studies.

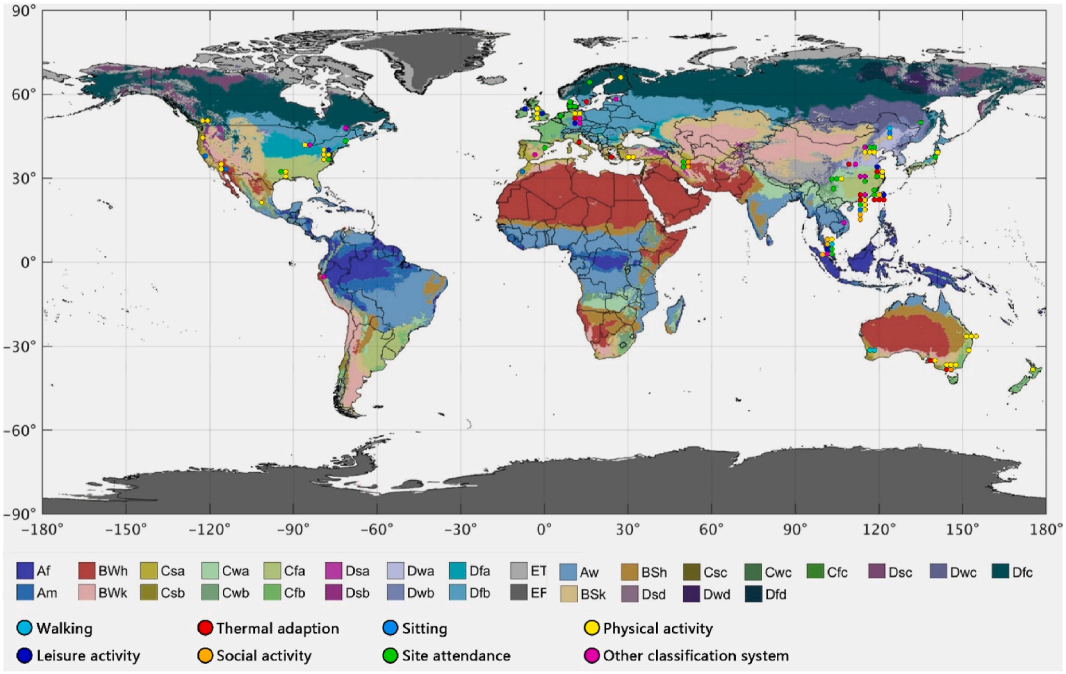

Fig. 5. Distribution of different types of research.

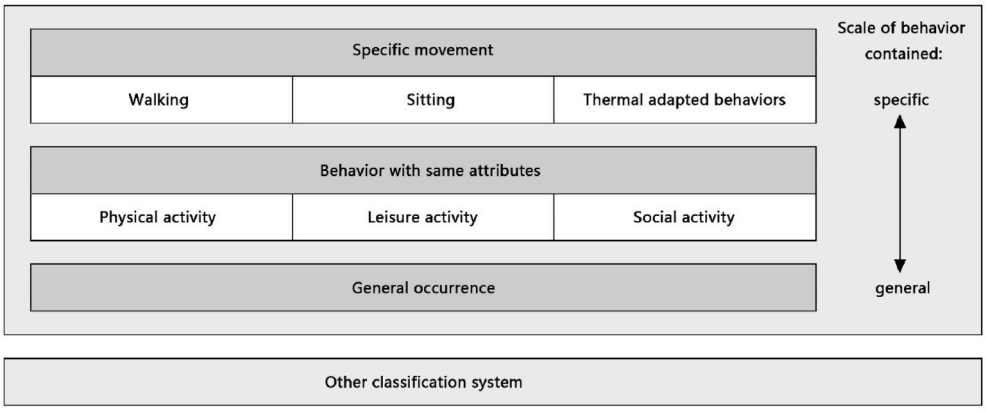

Fig. 6. Behaviour-based classification system.

climate conditions into account.

4. Types of behaviours

In existing research, different studies have been conducted on single as well as multiple types or categories of behaviours, and some of these behaviours have been studied quite frequently. To obtain a more systematic understanding of the behaviours being investigated, this study classified most common studied behaviours with the same characteristics as shown in Fig. 6 from a specific to a general scale. In this section, type of behaviours, including specific movements such as walking, sitting, and thermal adaption; categories of behaviours with the same attributes including physical activity, leisure activity, and social activity; site attendance without activity type specification; and other classification systems were differentiated.

4.1. Specific movements

4.1.1. Walking

As an activity highly linked with daily life and an important part of physical activity, walking in public open spaces has been studied in riverfront [45], greenways [46], squares [47] and other type of public open spaces [48] as shown in Table 1.

Distinguished from utilitarian walking as a means of transportation, walking study in public open spaces including pedestrian movement and crowding, baby strollers, and dog walking were mostly associated with recreational objective. In specific, large public open spaces and more facilities are associated with more walking [48]. Among all public open spaces within 1.6 km of home, high-quality local parks were found to be more effective in promoting recreational walking than average-quality parks [49]. Other factors, such as the acoustic environment were found could play important roles: the mean speed of those exhibiting walking with background music in the square was slower than when no background music was played [47]. In addition, neighbourhoods facilitators and barriers have been found could affect elder's outdoor mobility which direct correlate to movement and walking [50]. Among which greenery and green spaces, obstruction-free and non-slip footpaths, sheltered walkways, neighbourhood centre, and amenities were considered as facilitators. Uneven and obstructed footpaths, lack of shelter or shade, poor legibility, and overhead bridges were found to be barriers. Related to this, pleasure and comfort, psychosocial factors and motivation, materiality, temporality, and adaptive problem-solving behaviour were considered as underlying mechanisms [50].

4.1.2. Sitting

Outdoor sitting, mostly focused on and studied from the leisure and social dimensions, is different from indoor sedentary behaviour. Such behaviour is usually linked to the static state of the outdoor physical environment. Studies have also found that sitting is often a way of resting and offers the possibility of communicating with others as shown in Table 2.

In terms of overall distribution and tendency, owing to both physical and social needs, outdoor siting is especially important for the elderly. For example, in open spaces, outdoor seating was found to correlate with elderly residents' use of open spaces, which is highly impacted by the mean radiant temperature [51] associated with their thermal preferences. In addition, cultural background and region difference was found to be an influencing factor: under similar thermal environment, people in Morocco tended to sit more than Americans [52]. Surprisingly, the provision of seating was found to have no impact on use level [53] in some cases.

As the most common static state position in the outdoor environment, people's sitting positions, movements, and stay durations were found to be closely associated with the thermal environment and acoustic environment: sheltered seating was found to have a modest positive impact from February to April in San Francisco [53]; more people rested on the steps during a cool season than a hot season, and more than 75% of users preferred to remain in shaded areas and stayed there longer than in the sunlight in hot and humid climate [54]. And in squares, sitting behaviour were found could be changed due to music: when distance from the sound source increased, crowd density of sitting people were found decreased accordingly [47].

4.1.3. Thermal adaption

Unlike walking and sitting, thermal adaption is a set of serious types of behaviours that are widely examined in outdoor thermal studies. Behaviour adaption, including garment, body posture, beverage and food, physical activity, personal accessories, sun exposure, and showers have been widely studied in both indoor and outdoor environments [55,56]. Among them, overall stay, including space attendance, choice, and stay duration, as well as activity choices and location preferences, were closely linked with the outdoor built environment usage as shown in Table 3.

Thermal comfort is the most important factor affecting adaptation behaviour [57]. Because of the limited possibility and effectiveness provided, people prefer to seek adjustments in external environments [58] among which shading selection is the most studied behaviour, including that in tree-shaded and building-shaded places [59]. In addition, the overall attendance, distribution, and usage patterns could change greatly, according to previous studies [15,17,60,61]. Necessary, optional, and social activities decrease during outdoor heat stress more than that in any other thermal condition [62]. Choosing the most supportive thermal opportunities available within the place [55] and changing the activity spaces and activity times [56] were found to be helpful in coping with changes in the thermal environment.

The choice of outdoor activity is significantly affected by urban microclimate parameters, especially the indicators of temperature and solar radiation [62]. In addition, people's choices could also be strongly influenced by specific climate conditions linked with weather, season, and region difference. In hot and humid zones, people were found to prefer cool temperatures and weak sunlight, and adapted to thermal environments by seeking outdoor shelters in a public square [54,58,63].

Table 1
Factors investigated in papers focus on walking study.

Ref.	Background		Influencing factors		Subjective feedbacks		Location of investigation	year
	Research subjects	Research circumstances	Physical-based	Climate-based	feelings	health		
[47]	S1	P2	–	C3	F2	–	Harbin, China	2018
[48]	S1	P5	E4	–	F3	–	Perth, Australia	2005
[49]	S3	P1, P5	E4	–	–	–	Perth, Australia	2015
[50]	S2	P1	E1,E2,E3,E4	–	–	H2	Singapore	2022

S1	Subjects without specification	P5	Other circumstances	C3	Other climate-related influences
S2	Elders	E1	Greenery and greenspaces	F2	Physiological feeling and assessment
S3	Children & adolescents	E2	Shadings	F3	Circumstance perception & psychological evaluation
P1	Neighbourhoods	E3	Facilities & related components	H2	Long-term health impact
P2	Squares	E4	Other physical elements		

Table 2
Factors investigated in papers focus on sitting study.

Ref.	Background		Influencing factors		Subjective feedbacks		Location of investigation	year
	Research subjects	Research circumstances	Physical-based	Climate-based	feelings	health		
[47]	S1	P2	–	C3	F2	–	Harbin, China	2018
[51]	S2	P1	E3, E4	C2	–	–	Hong Kong, China	2021
[52]	S1	–	–	C1, C2	F2	–	Marrakech, Morocco; Phoenix, USA	2011
[53]	S1	P2	E3	C2	–	–	San Francisco, USA	2004

S1	Subjects without specification	C1	Seasonal climate influences	E3	Facilities & related components
S2	Elders	C2	Microclimate influences	E4	Other physical elements
P1	Neighbourhoods	C3	Other climate-related influences	F2	Physiological feeling and assessment
P2	Squares				

Table 3
Factors investigated in papers focus on thermal adaption.

Ref.	Background		Influencing factors		Subjective feedbacks		Location of investigation	year
	Research subjects	Research circumstances	Physical-based	Climate-based	feelings	health		
[22]	S1	P2	–	C1, C2	F2	–	Athens, Greece.	2007
[54]	S1	P2	E2	C1, C2	–	–	Taiwan, China	2015
[55]	S1	P4	–	C2	F2	–	Sweden	2004
[56]	S1	P1	–	C1, C2	F2	–	Guangzhou, China	2016
[57]	S1	P4	–	C2	F2	–	Shanghai, China	2015
[58]	S1	P4	E2	C2, C3	F2	–	Taiwan, China	2013
[59]	S1	P4	–	C2	F2	–	Hongkong, China	2018
[60]	S1	P2	E2	C2	–	–	Rome, Italy	2015
[15]	S2	P4	E4	C2	F2	–	Xi'an, China	2021
[17]	S1	P5	E2	C1, C2	F1	–	Melbourne, Australia.	2018
[61]	S1	P2	E4	C1, C2	F2, F3	–	Leipzig, Germany	2021
[62]	S1	–	E4	C2	F3	–	Adelaide, Australia	2017
[63]	S1	P2	–	C2	F2	–	Taiwan, China	2009

S1	Subjects without specification	P5	Other circumstances	C3	Other climate-related influences
S2	Elders	E2	Shadings	F1	Driving and needs
P1	Neighbourhoods	E4	Other physical elements	F2	Physiological feeling and assessment
P2	Squares	C1	Seasonal climate influences	F3	Circumstance perception & psychological evaluation
P4	Parks	C2	Microclimate influences		

In the Mediterranean area [22], people were found to prefer to sit in shaded areas in summer, whereas in autumn and winter sunlit areas were more popular.

4.2. Behaviour attributes

In addition to the specific types of movement mentioned above, some investigations were based on type of activity with same attributes. Among them, physical activity, leisure activity, and social activity were most frequently studied. In some instances, all three types of attributes could occur at the same time; for example, causal running with friends during leisure time could be labelled with all three attributes simultaneously.

The three behaviour attributes illustrated in Fig. 7 reflect a broad range of research interest. Physical activity, which is closely linked to the intensity of body movement, has been frequently studied due to its role in physical health. Leisure activities, with the objective and characteristic of relaxation and recreation, are usually mentioned in short-term restoration or emotional elevation studies. Social activity, which is a human need and impacts psychological feelings, was mostly studied associated with psychological health. Among all three behavioural attributes, physical activity has been studied the most.

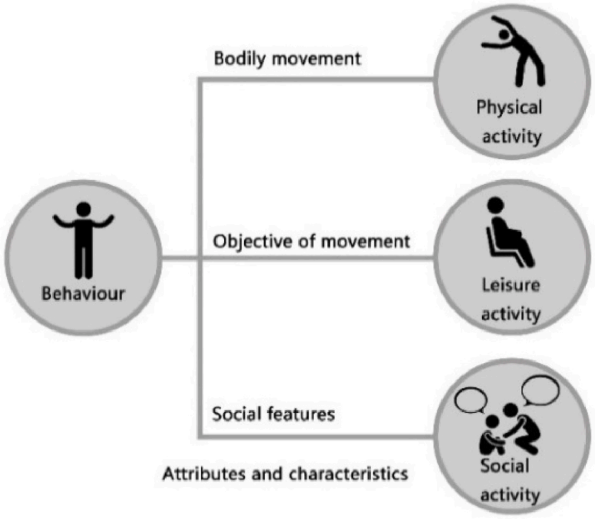

Fig. 7. Behaviour attributes.

4.2.1. Physical activity

Physical activity is a relatively broad concept that refers to any bodily movement produced by skeletal muscles by expending energy, which occurs during leisure time, for transport, or as part of a person's work [64], and which is highly associated with an individual's health condition [65]. Using sedentary behaviour as the baseline, physical activity can be classified into vigorous, moderate, and light intensity [66], and the first two categories, collectively referred to as MVPA (Moderate to Vigorous Physical Activity), have been widely studied [67–69] due to their relevance to physical fitness. In addition, as these three categories span a wide range of daily activities, other behavioural attributes including leisure [44] and social [34] factors were also

associated and taken into consideration.

To obtain a better understanding of what influences and shapes outdoor physical activity, various factors were considered as shown in Table 4. Among these, the outdoor climate environment is crucial [70] and has been examined in many studies. Effect of thermal comfort were found could greatly affect participants' physical activity attendance, duration, and frequency in green spaces [71]. The seasonal usage pattern of precincts and the role or function of places were found to influence people's presence outdoors [17]. A large number of people tend to delay exercise both in summer and winter; race, age, and education exacerbate the negative effects of adverse weather conditions on the decision to exercise outdoor [72]. Furthermore, the age of people could also create an impact: the number of counted park users, particularly the number of children and the elderly, was found to decline significantly at the highest temperature of approximately 30 °C [73].

Environmental constituents can have a strong impact on physical activity. Urban greenery and green space are the most frequently mentioned factors that are strongly associated with physical activity, especially for younger adults [74], women [75], and children [76]. Among them, greenery was found to have a significant impact on physical activity. Green coverage and shrub diversity were found to have a beneficial effect, whereas the shape of paved areas, visible greenery, and tree diversity were found to limit activity diversity [77]. The tree canopy and open grass were found to play different roles [67]. Greenness, behaviour settings [78], ground surfaces [78], fitness equipment and sports courts [79], and quality of design [80]. In addition, it has to be noted that the preference of types of elements differed among distinct age groups: young children mostly use playgrounds and natural lawn areas, while school children and teenagers tend to use the sports areas and semi-secluded spaces to practice sport or socialize, and for older people, sedentary activity was exclusively carried out on benches, and non-sedentary activities such as jogging were nearly exclusively occurred in the larger, more shaded places in discrepant parks [73]. In addition, people from different regions have different needs and preferences regarding outdoor facilities to practice physical activities [81].

Elements and facilities preferences, recommendations [65,82] and research focus on physical activity were diversified due to age groups. For older adults, some factors were found to be particularly important: social factors, physical capacity, and health status could impact their total physical activity [83]. Sites were found to play different roles in the

Table 4
Factors investigated in papers focus on physical activity.

Ref.	Background		Influencing factors		Subjective feedbacks		Location of investigation	year
	Research subjects	Research circumstances	Physical-based	Climate-based	feelings	health		
[20]	S1	P1	–	–	–	–	Brisbane, Australia	2010
[21]	S1	P1	–	–	–	–	Brisbane, Australia	2009
[19]	S3	–	E1, E4	C1	–	–	Bristol, UK.	2010
[44]	S1	P1	E4	–	F3	–	Cuernavaca, Mexico	2017
[67]	S1	P1	E1	–	–	–	Sydney, Wollongong; Newcastle, Australia	2021
[68]	S1	P1, P4	–	–	–	–	Los Angeles, US	2014
[69]	S2	P4	E3, E4	–	F3	–	Shanghai, China	2021
[70]	S1	P4	–	C2	F2	–	Malaysia	2013
[71]	S1	P4	E2	C2, C3	F2	–	Chongqing, China	2022
[72]	S1	–	–	C1	F4	–	USA	2019
[73]	S1	P4	E1, E2, E3, E4	C2	–	–	Leipzig, Germany	2020
[74]	S4	–	E1	–	F2, F3	–	China, Beijing	2015
[75]	S1	–	E1	–	–	–	Canada	2015
[76]	S3	–	E1, E4	C1	–	–	Bristol, UK.	2012
[77]	S1	P4	E1	–	–	–	Shanghai, China	2021
[78]	S3	P5	E3	–	–	–	North Carolina, USA	2010
[79]	S1	P4	E3	–	–	–	Melbourne, Australia	2021
[80]	S1	P5	E4	–	–	–	Texas, USA	2013
[81]	S2	P4	E3, E4	C1	F3	–	Hong Kong, China; Leipzig, Germany	2018
[83]	S2	P1	–	–	F3	–	Hongkong, China	2016
[13]	S4	P4	E4	–	–	–	Melbourne, Australia	2021
[84]	S3	P5	E1	–	F3	–	Aydın, Turkey	2020
[85]	S3	P4	E3	–	–	–	Melbourne, Australia	2020
[86]	S4	P1	E4	–	–	–	Japan	2020
[87]	S1	P1	E4	–	F1, F3	–	Washington, US	2008
[88]	S1	P1	E3	–	–	–	China, Beijing	2022
[89]	S1	P1	E1	–	–	H2	Finland	2015
[90]	S1	P4	–	–	F3	H2	Beijing, China	2017
[91]	S1	P1	E1	–	–	–	Hong Kong, China	2021
[92]	S1	P1	E1	–	F3	H2	Chicago, USA	2011
[93]	S3	P1	E1,E3,E4	–	F3	–	Changchun, China	2021
[94]	S2	P1	E4	–	F3	–	Vancouver, Canada; Portland, USA	2012
[95]	S2	P1	E4	–	F3	H2	Texas, USA	2018
[96]	S1	P2	E3	–	F3	–	Los Angeles, USA	2007
[97]	S1	P4	–	–	–	–	Washington, USA	2016
[98]	S1	P4	E4	–	–	–	Brisbane Australia	2020
[99]	S1	P4	–	–	F3	–	Adelaide, Australia	2014
[100]	S1	–	E1	–	F3	H2	Turkey	2016
[101]	S1	–	E1	–	–	H2	Bristol, UK	2010
[102]	S1	–	E1	–	–	H2	New Zealand	2013

S1	Subjects without specification	P5	Other circumstances	C3	Other climate-related influences
S2	Elders	E1	Greenery and greenspaces	F1	Driving and needs
S3	Children & adolescents	E2	Shadings	F2	Physiological feeling and assessment
S4	Other specific groups	E3	Facilities & related components	F3	Circumstance perception & psychological evaluation
P1	Neighbourhoods	E4	Other physical elements	F4	Other type of feelings
P2	Squares	C1	Seasonal climate influences	H2	Long-term health impact
P4	Parks	C2	Microclimate influences		

physical activity of the elderly. Among them, elderly visited urban parks frequently and most of the time was spent engaging in MVPA. The characteristics of being male, younger than 70 years, and in good health condition were found to be associated with a higher intensity of physical activity [69]. Further subdivided groups may have different preferences and user habits, such as green space usage for adolescents. Lack of greenery was found to be the most significant barrier for all participants. While boys were concerned about the characteristic features and design of urban green spaces, girls were concerned about accessibility and safety; younger adolescents were concerned about safety-related issues, while older adolescents were concerned about quality, time pressure, and peer-related issues [13,84]. Unlike adolescents, families with children prefer larger parks with a greater mixture of facilities and amenities [85]. Similar features have also been observed in other types of spaces [41].

Neighbourhoods are some of the most frequently studied places in studies of physical activity due to their close association with people's daily lives [20,21]. Neighbourhood quality is closely associated with not only the overall physical activity level [20] but also specific types of activity, such as dog walking [86]. Availability of sports facilities, parks, and bike racks, and simple interventions such as street lighting, pavements/sidewalks, street trees, benches, and traffic-calming devices, as well as utilitarian destinations in the neighbourhood, were found to be linked with higher odds of being physically active [87] although this may be caused by residential self-selection [88]. The environment surrounding residences and their recreational and commuting opportunities are believed to affect human health and well-being; among them, green spaces and greenery were found to be important factors [89–91]. The living context, quality of vegetation, and accessibility of urban green spaces have significant effects on residents' satisfaction levels [74] and are linked to stress mitigation [92]. Among all types of users in the neighbourhood, children and seniors were highlighted. Public open in neighbourhood were found closely associated with children's group activities and outdoor opportunities which could promote natural environment exposure and enhance overall physical activity level [93]. And the elderly was significantly highlighted owing to the higher odds of flexibility limitation and higher activity frequency. Among all types of attributes, safety and security, accessibility, comfort of movement, and peer support were found to be extremely important for the elderly [94]. Physical activities near the home could be supported by the design and planning of the environment, which is also linked with aging in place [95].

In addition to neighbourhood, other specific places were also studied and linked with physical activity studies. Among them, parks are highly mentioned [37] and have been found to play different roles in different types of communities [96]. Park users were positively associated with the number and duration of physical activities [97] and were more likely to meet the physical activity guidelines [98]. Park size was found to be positively associated with both overall participation and activity intensity [98]. Even a pocket park, when perceived as an attractive and safe destination, may increase physical activity by encouraging families with children to walk there [68].

In general, studies focusing on outdoor physical activity were interested in identifying its health benefits. The objective of outdoor physical activity mainly includes enjoying nature, getting exercise or improving fitness, releasing stress or reducing tension, enjoying tranquillity or avoiding crowds, spending time with friends, observing or studying nature, being around good people, doing something creative, connecting with family, thinking and reflecting, resting and relaxing, and spending time outside [99]; most of these purposes and behaviours could further affect people's health situations including physical health [72], mental health, and even aging processes. In addition, many objective factors and constituents mainly related to greenery accessibility and quality were found to promote physical activity, which further benefits health [100]. Accessibility and availability of greenery are significant to people's physical health. Close-to-home greenery implies a greater chance of leisure physical activity [89], the frequency of green space use declines as distance increases [101], and levels of physical activity are higher in greener neighbourhoods [102]. Thus, overweight and cardiovascular disease risks were found to be related to green space availability [101,102]. Due to the close connection mentioned before, many guidelines and recommendations offered by the WHO have focused on a more comprehensive relationship between physical activity and people's health situations [65,66,82,103].

4.2.2. Leisure activity

Without an official definition, leisure activity has been defined by some studies as participation in enjoyable activities during free time [104] (see Table 5). Some expanded the definition to include not only activities with less movement, but also intense physical activities done for recreation [37]. In general, leisure activities being studied were considered to be more associated with positive emotions and attention restoration due to the close connection and exposure to the natural environment compared with indoor leisure. Related investigations in small-scale outdoor environments have primarily focused on the outdoor influence of people under relatively static conditions. Among them, different leisure activities such as sitting, relaxing, and strolling, and different types of natural views such as green elements, sight views, and materials may contribute differently to emotion enhancement, attention restoration, and stress alleviation [105].

To study the factors influencing leisure activities, the short-term restorative process and deep-seated reasons have been studied. Among them, different types of restorative components in small urban parks have been found to play different roles among which natural waterscapes have been highlighted in some studies [14,106,107]. In addition to these components, comfort, convenience, and safety are considered to affect leisure activity, especially at night [108].

In the process to study the impact brought by leisure activity, green spaces could play important roles [109]. As a mediator factor for negative emotion created due to spill over effect during work, solitary strolls and park visits were found to provide greater psychological benefits to working mothers compared with picnics [105] which are considered as a leisure activity with social attributes. In contrast to working mothers, older people seem to rely more on social relationships during leisure activities [110]; perceptions of positive social relationships were associated with greater involvement in leisure activities and further associated with better health situations [110].

4.2.3. Social activity

Social factors are one of the main attributes that influence outdoor behaviour. Social behaviour was less focused on the outdoor environment than physical activity. Because many activities can contribute to social support or social attributes, social activity is a relatively broad concept. Social environment has been divided into five dimensions: social support and social networks, socioeconomic position and income inequality, racial discrimination, social cohesion and social capital, and neighbourhood factors [34]. Among them, social support is closely connected with public open spaces due to its close link with fear of crime [111]. In some studies, social factors were considered to influence the conduct of physical behaviour [34] and highly linked outdoor activity choices under extreme weather conditions [62] as shown in Table 6.

The influence of social interactions on the behavioural patterns of people in urban spaces has been proven to be strongly linked to the quality of the built environment [112]. Different influencing factors, including different periods [113,114], privatized features [115], and age groups [16] were found to have different influences. Among these factors, neighbourhood [92] and the elderly have been well studied. Perceptions of positive social relationships are associated with greater involvement in leisure activities, and greater involvement in leisure activities is associated with better health in older age [110]. Talking with friends and meeting new friends during social and physical activities seem to be one of the main reasons for the elderly going to public

Table 5
Factors investigated in papers focus on leisure activity.

Ref.	Background		Influencing factors		Subjective feedbacks		Location of investigation	year
	Research subjects	Research circumstances	Physical-based	Climate-based	feelings	health		
[105]	S4	–	E1	–	F3	H1	Taiwan, China	2017
[106]	S4	P5	E4	–	–	–	Jiangsu, China	2021
[107]	S3	–	E4	–	–	–	Sheffield, UK	2020
[14]	S1	P4, P5	E4	–	F3	H2	Germany	2015
[108]	S1	P1, P4	E4	C3	F3	–	Malaysia	2013
[109]	S1	P4	E1, E4	–	F3, F4	–	Ireland, UK	2020
[110]	S2	–	–	–	–	H2	USA	2014

S1	Subjects without specification	P4	Parks	F3	Circumstance perception & psychological evaluation
S2	Elders	P5	Other circumstances	F4	Other type of feelings
S3	Children & adolescents	E1	Greenery and greenspaces	H1	Short-term health impact
S4	Other specific groups	E4	Other physical elements	H2	Long-term health impact
P1	Neighbourhoods	C3	Other climate-related influences		

Table 6
Factors investigated in papers focus on social activity.

Ref.	Background		Influencing factors		Subjective feedbacks		Location of investigation	year
	Research subjects	Research circumstances	Physical-based	Climate-based	feelings	health		
[46]	S2	P1	E4	–	F3	–	Taiwan, China	2020
[111]	S1	P1	E4	–	F3	–	Tehran, Iran	2015
[112]	S1	P2	–	–	–	–	Rasht, Iran	2020
[113]	S1	P1, P4	–	–	F3	–	Malaysia	2012
[114]	S1	P1, P4	–	–	–	–	Malaysia	2012
[115]	S1	P2	E4	–	F3	–	Medan, Indonesia	2012
[16]	S4	P4	E4	–	F3	–	Melbourne, Australia	2021
[116]	S2	P5	E3	–	F1, F3	–	Hongkong, China	2016
[117]	S2	P4	–	C1, C2	F2	–	Hong kong, China	2019

S1	Subjects without specification	P4	Parks	C2	Microclimate influences
S2	Elders	P5	Other circumstances	F1	Driving and needs
S4	Other specific groups	E3	Facilities & related components	F2	Physiological feeling and assessment
P1	Neighbourhoods	E4	Other physical elements	F3	Circumstance perception & psychological evaluation
P2	Squares	C1	Seasonal climate influences		

open spaces [116]. In addition, for elderly people living in a similar context, social capital has been found to be one of the main factors influencing overall outdoor activity [46]. For elderly people with outdoor social objects, better thermal acceptability was observed among all outdoor usage patterns [117].

Overall, although physical activity, leisure activity, and social activity overlap in many specific actions and movements, the characteristics and emphasis of studies conducted were different: investigations of physical activity focused more on the environmental impact on dynamic behaviour, among which exercise was highlighted; research on leisure activity focused more on the environmental impact on relative statistic behaviour, people's feelings, preferences, and evaluations were emphasized and studied; research on social activity focused more on the influence between people and behaviour, among which outdoor sites' public attributes are highlighted. Moreover, compared with most studies of specific movements that only take simple distribution and influencing factors into consideration, studies of categories of behaviours have considered more deep-seated influencing factors. More specific perceptions and evaluations, people's psychological feelings, and physiological feelings are involved. In addition, the effect of behaviour, which mainly includes people's health situations, was studied further.

4.3. Site attendance

In addition to the specified types of activity, the investigation of general site attendance could generally represent space quality, outdoor preference, and people's using habit. Due to this, site attendance was investigated in some studies that quantified different parameters, including the number of attendance [118,119], visitation frequency [120], duration [121], distribution [18,122–124], and usage rate [125] as shown in Table 7. Among all research based on site attendance investigation, climate–behaviour interaction and usage pattern study were the two most focused topics.

Place-related behaviour based on outdoor climate investigation was commonly considered and investigated without specifying the behaviour types. Heat loads based on different sites may differ and further impact the usage and levels of activity [126]. Moreover, people's attendance is significantly influenced by weather assessment which includes factors such as thermal comfort, place perceptions, sky view factor, specific types of thermal indices, and seasonal differences [127–131]. Not only the number of attendees, but people's frequency, duration, and spatial-temporal distribution may also differ due to biometeorological indices and comfort differences [132].

Studies focus on usage habit investigation were mostly based on location or time period with specific features. Without a specific focus on activity attributes, people's preferred habits were the primary study subjects [133,134]. Less studied outdoor spaces such as nursing home [135], children's hospital [136], workplaces [137], and the specific usage patten during lockdown or pandemic were also investigated [138–140].

4.4. Alterative classification system

In addition to the aforementioned categories of behaviour, different classification methods have been applied in other studies (see Table 8).

People's behaviour was divided into detailed actions such as walking, standing, cycling, jogging [142,143], swimming, sitting, picnic, sunbathing and play [144,145]. It helps capture the characteristics of behaviour but often involves larger and more complicated data processing compared with the three-attribute approach.

Table 7
Factors investigated in papers focus on site attendance.

Ref.	Background		Influencing factors		Subjective feedbacks		Location of investigation	year
	Research subjects	Research circumstances	Physical-based	Climate-based	feelings	health		
[118]	S1	P4	E1	–	F3	–	Barcelona, Spain	2022
[119]	S1	P5	E1	–	F1	–	Denmark	2010
[120]	S1	P5	E1	–	–	–	Odense, Denmark	2010
[121]	S1	P4	E4	–	–	–	Beijing, China	2020
[18]	S1	P4	–	–	–	–	Shanghai, China	2020
[122]	S1	P4	–	–	F1, F3, F4	–	Singapore	2019
[123]	S1	P5	E4	–	F3	–	/	2022
[124]	S1	P5	E4	–	F3	–	Yunnan, China	2020
[125]	S1	P1	–	C2	F2	–	Wuhan, China	2014
[126]	S1	–	–	C2	F1, F2, F3	–	Tokyo, Japan	2007
[127]	S1	P2	E4	C2	F3	H1	Hongkong, China; Singapore	2017
[128]	S1	P2	E4	C2	F2, F3	–	Netherlands	2010
[129]	S1	–	E2	C2	F3	–	Gothenburg, Sweden	2007
[130]	S1	P4	E2	C2	F2	–	Taiwan, China	2012
[131]	S1	P2	–	C2	F2	–	Esfahan, Iran	2012
[132]	S1	P4	–	C2	–	–	Chongqing, China	2021
[133]	S1	P2	E3	–	–	–	Khabarovsk, Russia	2021
[134]	S1	P4	E2	C2	–	–	Massa chusetts, USA	2017
[135]	S2	P5	E4	–	F3	–	Beijing, China	2021
[136]	S1	P5	E4	–	–	–	Texas, USA	2013
[137]	S1	P5	–	–	F3	–	Denmark	2012
[138]	S1	P5	–	–	–	–	Virginia, U. S.A.	2021
[139]	S1	P4	–	–	F3	–	Iran	2021
[140]	S1	P4	E1	–	–	H2	Chengdu, China	2020
[141]	S1	P4	–	C2	F2	–	Taiwan, China	2013

S1	Subjects without specification	E1	Greenery and greenspaces	F2	Physiological feeling and assessment
S2	Elders	E2	Shadings	F3	Circumstance perception & psychological evaluation
P1	Neighbourhoods	E3	Facilities & related components	F4	Other type of feelings
P2	Squares	E4	Other physical elements	H1	Short-term health impact
P4	Parks	C2	Microclimate influences	H2	Long-term health impact
P5	Other circumstances	F1	Driving and needs		

Table 8
Factors investigated in papers based on alternative classification system.

Ref.	Background		Influencing factors		Subjective feedbacks		Location of investigation	year
	Research subjects	Research circumstances	Physical-based	Climate-based	feelings	health		
[45]	S1,S3	P3	E4	–	–	–	Frankfurt, Germany	2020
[142]	S2	P5	E4	C3	–	–	Tianjin, China	2020
[143]	S1	P2	E1, E2, E3, E4	–	–	–	Shenzhen, China	2016
[144]	S1	P5	E4	C1	–	–	Tallinn, Estonia	2014
[145]	S1	P4	E3	–	–	–	Zhengzhou, China	2020
[146]	S1	P4	E4	C3	F3	–	Vietnam	2019
[147]	S2	P1	E1, E3, E4	C3	–	–	Nanjing, China	2021
[148]	S1	P5	E3	–	F3	–	Ecuador	2017
[149]	S1	–	E2	C2	–	–	Montreal, Canada	2001
[150]	S1	–	E1	–	F3	H1	/	2019
[151]	S1	–	–	C1, C2	F2	–	Wuhan. China	2016
[152]	S3	P5	E3	–	–	–	Michigan USA	2021
[153]	S1	–	E1	–	–	–	Granada, Spain	2014
[154]	S1	P1	E1	–	F3	–	Berlin, Germany	2021
[155]	S1	P1, P4	E1	–	–	–	Malaysia	2015

S1	Subjects without specification	P4	Parks	C1	Seasonal climate influences
S2	Elders	P5	Other circumstances	C2	Microclimate influences
S3	Children & adolescents	E1	Greenery and greenspaces	C3	Other climate-related influences
P1	Neighbourhoods	E2	Shadings	F2	Physiological feeling and assessment
P2	Squares	E3	Facilities & related components	F3	Circumstance perception & psychological evaluation
P3	Streets	E4	Other physical elements	H1	Short-term health impact

Some studies have focused on specific needs and objectives. For example, residents' behaviour in parks was classified as health-related, social interactive, recreational, and other activities [146]. For seniors living in old residential communities were divided into social activities, leisure activities, utilitarian-type activities, nature-exposure activities [147]. For studies on riverbanks, people's behaviours were distinguished, including recreational, productive, and daily activities [148] in order to facilitate comparisons and analysis related to environmental quality.

Body status have been highlighted in some of the previous studies. Mobile activities and stationary activities have been firstly distinguished in a pedestrian street investigation [45]. And Body state including walking, standing, and seating seems could play different roles when facing specified influencing factors. Owing to the difference in energy consumption, thermal feeling, and environmental exposure, behavioural differences were found between sitting and standing. A strong linear relationship was found between sitting behaviour and air temperature, regardless of the presence of the sun [149]. Not only thermal

comfort but also people's status was highly linked with the general feeling and feedback of outdoor spaces. Green space behaviour, walking, and sitting were found to have different psychophysiological responses to green space visitors [150].

A specific classification system was applied [151] based on the intensity of physical activity and specific children's activity coding system [152]. The system for observing play and recreation in communities (SOPARC) was used to study visitors' behaviour and characteristics, mainly including relaxation, exercise, and walking in a park [153]. Physical activity can also be divided into passive and active physical activities, which are mainly based on the intensity of physical activity [154,155].

5. Subjective feedbacks associated in behaviour studies

Considered associated with outdoor activity and space usage, some subjective factors were also frequently investigated in behaviour-based studies. Among them, the behaviour-feeling interaction, and activities' health impact have been most frequently mentioned. In specific, the behaviour-related subjective feedbacks could be categorised as shown in Fig. 8. Associated with activity conducted in both before and after stage, type of feelings commonly mentioned in existing studies could be summarised as driving and needs, psychological feeling, and psychological feeling; outdoor activities' long-term and short-term health impact could also be distinguished.

In terms of research distribution, linkages among feeling, type of behaviour, and health impact are shown in Fig. 9. Factors in the same paper were linked. The higher number of articles discussing the topics, the thicker lines are. Psychological feelings and environmental perceptions are often studied together with physical activity (as illustrated in yellow lines), and they have further linkage with long-term health impact. It is noticeable that studies that investigated physiological feelings were also focused on thermal adaption (shown in orange lines) and overall occurrence (shown in green lines). In addition, long-term health was studied more often than short-term impact associated with activity in public open spaces, among which physical activity has accounted for a large proportion.

5.1. Feelings

5.1.1. Driving and needs

As original reasons for outdoor space usage, the needs of specific sites are distinct and are considered as key influential factors; people's needs were specifically focused and studied in some cases [122].

Specifically, the importance of needs was found to differ due to respondents' groups, and some of them were specifically highlighted; for example, the importance of social needs has been highlighted for elderly studies [156]: social and physical activities, as well as the community life facilities and services, social network, and clean and pleasant environment were found to be the most important needs [116] of the elderly. In addition, benefits were considered drivers of people's behaviour, and in some studies, they were further categorised into four groups: psychological, physical, environmental, and social aspects [99].

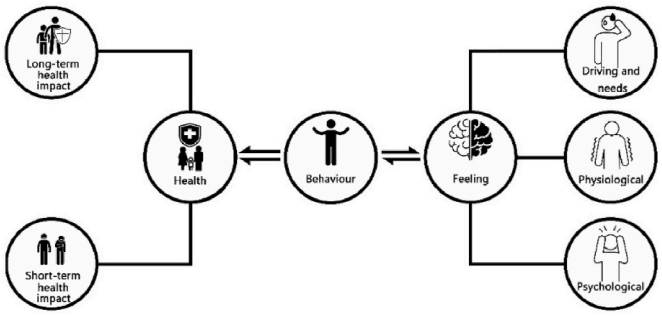

Fig. 8. Behaviour-related feedbacks.

5.1.2. Physiological feeling and assessment

Unless in-depth factors are associated with self-esteem, cognition, culture, and mood, climate factors that could affect thermal comfort and physiological feeling are mainly associated with the general occurrence of sites [58,129,134]. Factors including time exposure, expectations, experience, and perceived control may influence environmental assessment [55] and other factors, including individual, physical, social, and psychological discrepancies [117,157] were found to cause physiological differences.

Configurations including spatial features, structures, and materials [128,158] can affect environmental perception, leading to different thermal acceptance. In addition, people's background, living area, and thermal experience have been found to impact tolerance, perception, and thermal feeling [63,159,160].

5.1.3. Environmental perception and psychological evaluation

Environmental perception, which can directly impact people's outdoor behaviour, is highly mentioned. To obtain people's overall perceived quality, vegetation, facilities, and discouraged staff were considered and investigated using rating systems for parks and green spaces [74]. Serene was found to have more impact and higher odds of impacting time spent outdoors in the workplace [137]. In contrast to outdoor open spaces, perceived qualities including street connectivity, infrastructure and safety, safety from traffic, safety from crime, few cul-de-sacs, barriers, and busy roads were found to have more influence on streets and neighbourhoods [23,40,44]. In addition, perceived accessibility to parks or green spaces was also highly mentioned, which could impact overall usage compared with residents' attitudes and subjective norms, which could elevate respondents' satisfaction levels [74,122].

After outdoor usage and stay, people's environmental evaluations, including diverse aspects, were considered. Aesthetics, safety, overall satisfaction, and emotional affection were the most frequently studied topics. Aesthetics are influential factors that have been studied and associated with various types of activities and locations such as walking and physical activity in parks, neighbourhoods, and other open spaces [23,40,44,161,162]. Compared with other perceived qualities, aesthetics has a broad international impact [23]. Outdoor features and components, such as urban blue, which is frequently linked to higher aesthetic quality, were found to be closely linked to users' recreational activity and feelings [106,123]. Safety is also frequently mentioned: characteristics of open spaces, such as the presence of lighting, visibility of surrounding houses or roads, type of surrounding roads, presence of crossings [48], and social interactions such as social support, were considered related [111]. Among all responses, women felt less safe [61, 163]. Satisfaction, as a comprehensive evaluation indicator, is the most common feedback reflecting people's general feelings. Satisfaction has been used to measure environmental features and quality [74], thermal environment [117] and other influencing factors [115]. People's well-being and place attachment [123,164] as a specific type of satisfaction, have also been studied. In addition, people's moods and emotions are important psychological reactions. Self-emotion restoration assessment, including general evaluation [90], specific subjects of joy and contents [105], or aspects including elated to bored, glad to gloomy, calm to nervous, and active to passive [165] have been investigated in existing studies. Activities such as physical activity in urban parks [90] or leisure activities in green spaces [105] were found to promote positive emotions, elevate mood, and relieve stress caused by work-family conflict in working mothers.

5.2. Health impact

Health impacts of outdoor activity have also been frequently

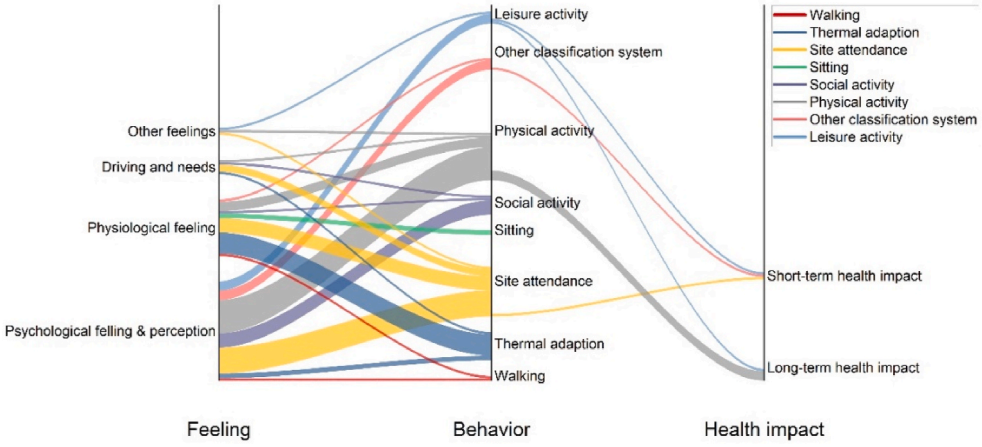

Fig. 9. Distribution of subjective feedbacks.

investigated in public open spaces. Possible causative mechanisms include the provision of physical activity opportunities, stress-relieving effects of nature during outdoor leisure [164], and facilitation of social contacts [102,109,110]. Such health-enhancing effects are found to differ due to the population of users [105] and space composition [14], and other health-related processes, such as the aging process, are also affected [95].

5.2.1. Short-term impact

Among all kinds of outdoor composition, greenery has been highly mentioned due to its restorative and healing functions [150]. The level of space enclosure and greenery density were found to be associated with healing evaluation in green open space [127]. Greenery could improve the participants' attention, and the restorative effect could increase corresponding to greenery awareness [166] and a dose-response association was found between density of tree cover and respondents stress-reducing [167]. In addition, such process is always linked to leisure activities [105].

5.2.2. Long-term impact

Greenery were also found could promote long-term health impact [38]. Closely associated with physical, leisure, and social activity promotion, greenery accessibility were found could greatly influence physio-psychological health [92,101,168,169]. Due to this, the influence of neighbourhood greenery have been highlighted in lots of investigations and found closely associated with both mental and physical health situation [100,102] including cardiovascular disease, birth and mortality outcomes [38]. In addition, urban blue [14] and overall quality [3] were also found associated with people's feeling and mental health.

6. The changes through COVID-19 pandemic

In the past two and half years, to slow down the transmission of the COVID-19 across the world, unprecedented steps such as lockdowns and other policies have been implemented. People's daily lives, including work and study, mobility patterns, and social interactions, have been greatly influenced [170,171]. People's behavioural patterns and needs have changed correspondingly. Overall, The needs of natural environment have been raised [172], and such improvement is largely related to people's attention to physical and mental health [173].

6.1. Investigations after the first outbreak of COVID-19

Based on this, investigations have been changed correspondingly in public open spaces. To get a more comprehensive understanding of studies conducted, papers published after year 2020 were extracted and analysed as shown in Fig. 10. Among all 116 papers reviewed, 41 papers were published since then, and among them 4 papers [45,138–140] have highlighted the influence of pandemic. Among them, activities being studied in the pandemic scenario were relatively simple and indistinct. Most papers were based on the site attendance investigation, and specific characters and attributes of behaviours haven't gotten special attention.

In addition, subjective feedbacks and objective influencing factors associated with people's behaviour were analysed in Fig. 11 using open-source network analysis software Gephi based on the classification system proposed in section 4. Although the factors being studied were not able to form a relatively complete system due to the small number of studies after the first outbreak (as shown in red lines in Fig. 11), site attendance is the main subject to be investigated after the first outbreak of COVID-19.

6.2. Changes in COVID-19 pandemic

Based on the papers reviewed, some changes could be noticed due to the pandemic. Among them, facial coverings wearing have become a new type of activity being studied [138]; perceived risk was studied as a new indicator closely associated with users' vulnerability and decision-making [139]; space enclosure due to covid was also found closely associated with outdoor behaviour pattern and space usage [45].

In addition, due to the impact from the pandemic, some attributes of outdoor activity have become ever more important [174]. The need for outdoor physical activity and social activity has greatly increased. Closely associated with people's well-being [175] and health condition in both physical and mental aspects [176], physical activity promotion have been highlighted [177]. Furthermore, though maintaining social distance is important, close contact in an outdoor environment is still much safer than in an indoor environment. Promoting physical activity and social activity to meet people's needs while maintaining safety has become an important topic in public open spaces.

In terms of influencing factors associated, adjustments should also be made. Owing to the limited usage of public open spaces [178] and the change in activity distance, how to make public spaces meet people's needs has become more important. People's outdoor choices are limited and have been more concentrated in accessible areas such as neighbourhoods and residential areas especially in high-density urban spaces. Small and narrow open spaces that have been previously less focused, such as pocket parks, should receive more attention [179]. In addition, to offset the adverse effects such as stress and low well-being brought about by the lockdown, subjective assessment and feeling during outdoor activities have become more important.

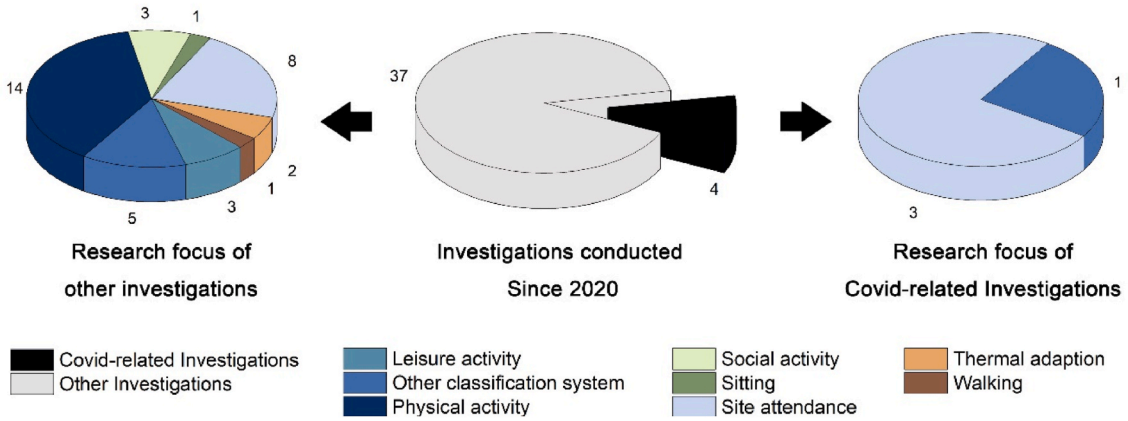

Fig. 10. Investigation and research focus since 2020.

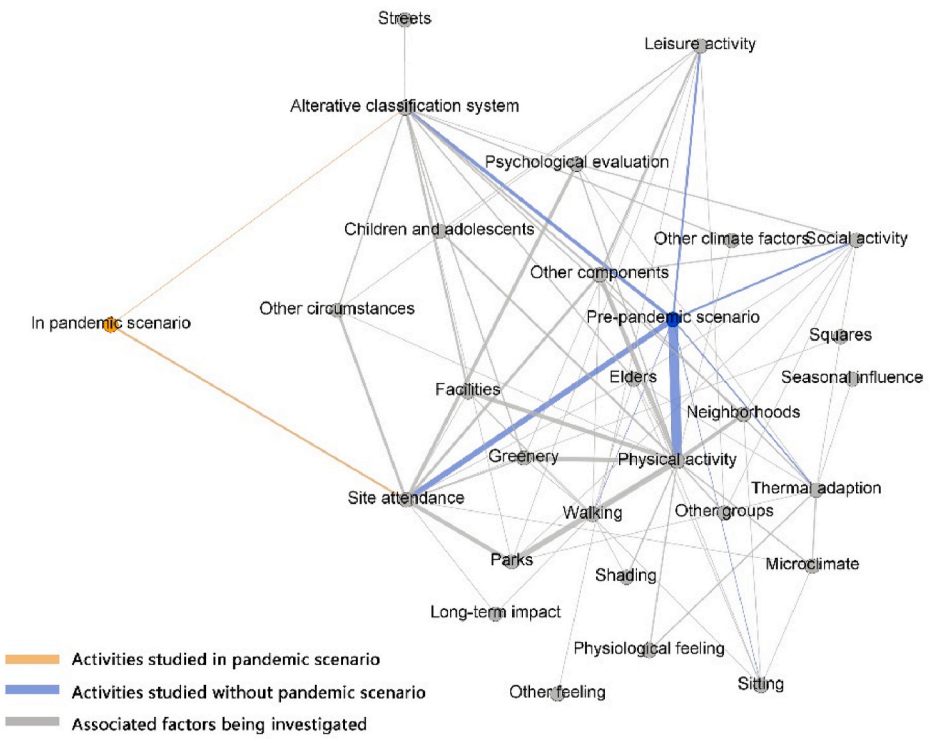

Fig. 11. Factors associated in studies since 2020.

In addition, behaviour patterns in public open spaces largely differed due to people's perceived risk [139] and governments' anti-epidemic policies. Due to this, some studies reviewed were shown discrepant results. In different regions, such indicators may have a huge difference. Thus, types of studies and related research setups should be adjusted accordingly to regional differences.

In general, the pandemic has become a great influencing factor in outdoor space usage. The effect of the pandemic should be taken into concern in future behaviour-based studies.

7. Conclusion

This study followed the PRISMA methodology and carried out a systematic review of behaviour-based studies on public open spaces. 116 studies related using quantitative-based investigation methods were identified, categorised, analysed, and specified reviewed.

The main contributions of this review are that: (1) this article proposed a relatively complete system that categorises people's behaviour in public open spaces; (2) it introduced outdoor subjective influencing procedure including behaviour, feeling and health impacts; (3) the review illustrated the distribution of existing research as well as research trends; and finally (4) the article also timely discussed the influence of the COVID-19 on people's behaviour in public open spaces.

In specific, background information, state of art, and general structure of this paper were first presented. Review method applied were then introduced in Section 2. Procedures including database selection and paper identification, search records screening, full text eligibility check, and paper inclusion were specified introduced. After that, a general introduction of existing studies is presented in Section 3. Most frequently studied factors in behaviour-based studies were robust categorised, type of behaviours, behaviour related subjective feedbacks, and objective influencing factors were distinguished. Time-based and region-based distribution of recent studies were analysed. Based on this, a more specified introduction based on behaviour category were conduct in Section 4. Outdoor behaviour categorised as specific movement including walking, sitting and thermal adaption; activity with the

same attributes including physical activity, leisure activity, and social activity; site attendance; and alternative classification systems were specified introduced. In Section 5, subjective feedbacks associated in behaviour studies were discussed. Interaction between type of feelings including driving and needs, physiological feeling and assessment, environmental perception, and psychological evaluation; health effect including short-term impact and long-term impact were specified. Based on aforementioned influencing procedure, behaviour change occurred during COVID-19 pandemic were highlighted in Section 6.

7.1. Future research

Moving forward, several areas should be focused and examined in future studies: (1) Currently, large difference could be found in types of behaviour being studied. Some behaviours in public open spaces were less concerned and have not been in-depth studied. (2) Though types of feelings and subjective feedbacks have been investigated associated with outdoor space usage. Besides few points frequently mentioned, subjective influencing procedure is still far from compete. (3) Most investigations conducted was distributed in relatively concentrated regions. Developed countries and mild climate zones have received huge concern while less developed countries and district with extreme climate were neglected though they should, in fact, received more attention. (4) Until now, several studies have highlighted the influence of COVID-19 in public open spaces. Activities being studied in the pandemic scenario were relatively simple and indistinct. Due to the outbreak of COVID-19, pattern of space usage has been changed greatly and it could have a long-lasting impact. Therefore, the long-term impact of the pandemic should be investigated in future.

7.2. Limitation

Although the most frequently studied factors in behaviour-related investigations were extracted and listed, this review is limited due to its scope and words limit. A large number of studies that consider outdoor occurrence as background and focus on subjective feedback investigation were neglected. As main part of outdoor influencing procedure which closely associated with public open space usage, these investigations should also be considered as a separate review.

Overall, the interaction between public open spaces and types of behaviour is illuminated in this review. This paper offers a comprehensive summary of outdoor behaviour studies that could benefit engineers, designers, scientists, and provide a better basis for subsequent research.

CRediT authorship contribution statement

Shuyan Han: Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation. **Dexuan Song:** Writing – review & editing, Supervision, Resources, Project administration, Methodology, Investigation, Conceptualization. **Leiqing Xu:** Writing – review & editing, Supervision, Funding acquisition, Conceptualization. **Yu Ye:** Writing – review & editing, Supervision, Methodology, Investigation. **Shurui Yan:** Writing – review & editing, Software, Investigation. **Feng Shi:** Writing – review & editing, Supervision. **Yuhao Zhang:** Writing – review & editing, Investigation. **Xiaodong Liu:** Writing – review & editing, Validation. **Hu Du:** Writing – review & editing, Writing – original draft, Visualization, Supervision, Methodology, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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