Ingi, Dmitrii; Bhusal, Pramod; Pinho, Paulo; Kyttä-Pirjola, Marketta; Parker, Martin

Ways to study changes in pedestrians' behaviour in the artificially lit urban outdoor environment

Published in:
IOP Conference Series: Earth and Environmental Science

DOI:
10.1088/1755-1315/1099/1/012007

Published: 24/11/2022

Document Version
Publisher's PDF, also known as Version of record

Please cite the original version:
Ingi, D., Bhusal, P., Pinho, P., Kyttä-Pirjola, M., & Parker, M. (2022). Ways to study changes in pedestrians' behaviour in the artificially lit urban outdoor environment. *IOP Conference Series: Earth and Environmental Science*, *1099*(1), 1. [012007]. https://doi.org/10.1088/1755-1315/1099/1/012007

IOP Conference Series: Earth and Environmental Science

PAPER • OPEN ACCESS

Ways to study changes in pedestrians' behaviour in the artificially lit urban outdoor environment

To cite this article: Dmitrii Ingi *et al* 2022 *IOP Conf. Ser.: Earth Environ. Sci.* **1099** 012007

Ways to study changes in pedestrians' behaviour in the artificially lit urban outdoor environment

Dmitrii Ingi, Pramod Bhusal, Paulo Pinho, Marketta Kyttä, Martin Parker

dmitrii.ingi@aalto.fi, pramod.bhusal@aalto.fi, paulo.pinho@aalto.fi, marketta.kytta@aalto.fi, martin.parker@taltech.ee

dmitrii.ingi@aalto.fi

Abstract. Lighting technologies have been rapidly developing in recent years together with the advancement in digital and connected technologies. Nevertheless, while achieving quantitative goals with the help of technical developments, there is always a need to correlate them with their impacts on users' experience. This paper focuses on the changes in human behaviour whilst walking under an artificially lit outdoor environment. A systematic literature search was conducted from which three groups of a pedestrians' behaviour were identified, namely walking (including activity levels and walking patterns), microscopic mobility (including walking speed, gait characteristics and use of walkway space) and gaze behaviour. An additional round of a literature search was done for each of the group mentioned above. Final set of the articles consisted of 41, 13 and 12 papers for walking, microscopic mobility behaviour and gaze behaviour subgroups respectively. The existing knowledge on possible changes in pedestrian behaviour caused by various artificial lighting settings was summarized. In addition, the methods to gather data about these changes applied in the selected papers were reviewed, and the perspectives for video-based analysis and online public participation geographic information system methodologies were discussed.

1. Introduction

The role which outdoor lighting plays in our current, 24/7-world cannot be underestimated. Due to different layers of artificial outdoor lighting, people can continue their activities after dark, feel safer and enjoy the urban environment. It goes without saying that leisure time for most people, including their necessary, optional, and social activities, is held after dark when they have finally completed a workday. In addition, people who need to work night shifts also use outdoor public spaces intensively even during night hours. The lighting aspect is particularly relevant in the autumn and winter periods in the northern countries when daylight hours are significantly reduced.

Lighting technologies have been rapidly developing in recent years together with the advancement in digital and connected technologies. Nevertheless, while achieving quantitative goals with the help of technical developments, there is always a need to correlate them with their impacts on users' experience. The evaluation of pedestrian experience in the lit environment can be approached based on three types of human responses: perception, evaluation, and behaviour [1]. These responses to lighting were systematically reviewed by J. Rahm in his doctoral thesis [2]. While methods to study pedestrians' perception and their evaluations are sufficiently developed to implement them in real-world studies, methods to study changes in pedestrians' behaviour are less known and usually limited with direct observations. However, to fully evaluate pedestrians' experience in the lit environment lighting professionals need to analyse and correlate the data of all three human responses mentioned above. This paper focuses on behavioural aspects of the pedestrian experience in the artificially lit urban outdoor environment, as well as on the review of different data collection methods used to study changes in a pedestrian behaviour.

The first objective of this paper is to summarise and analyse existing knowledge on possible changes in pedestrian behaviour caused by various artificial lighting settings (e.g., characteristics and targeted lighting design). Secondly, it reviews and compares methods to gather data about changes in pedestrian behaviour applied in the selected papers, identifying and discussing perspectives for authors' upcoming experiments.

2. Method

A systematic literature search was conducted between December 2021 and February 2022 by the author of the paper. The flowchart of the process is shown in Fig.1. The initial keywords in this work were pedestrian* AND light* AND behav*. The terms were searched in titles, abstracts, and keywords of the papers in two digital databases: Scopus and Web of Science. After the abstracts' screening and filtering process, a set of articles (21) was identified using key inclusion and exclusion criteria listed below. Then selected papers were fully read and topically grouped into three main subgroups, namely walking (including activity levels and walking patterns), microscopic mobility behaviour (including walking speed, gait characteristics and use of walkway space) and gaze behaviour. Relevant articles used as references in the selected set were also included in the final set. Afterwards, building upon reading material, additional search terms mentioned in the flowchart were used for the second round of a literature search with the same key inclusion and exclusion criteria. The second round was conducted in three digital databases: Scopus, Web of Science and Google Scholar. Final set of the articles consisted of 41, 13 and 12 papers for walking, microscopic mobility behaviour and gaze behaviour subgroups respectively. It is important to declare that some articles simultaneously covered several topics (e.g., speed of walk and gaze behaviour). Selected papers were fully read and analysed to achieve previously stated aims.

In addition, it is worth noting that there were 7 papers which also described behaviour although could not be linked with the three identified groups that were harvested during the second round. They will be mentioned in the 4th chapter.

Key inclusion criteria:

- Studies are dedicated to any type of pedestrian behaviour after dark.
- Both laboratory and field studies which focus on outdoor or public spaces experiences.
- All scientific publications available in English including reviews, conference papers, book's chapters.
- Availability of the study's results and a method description.

Key exclusion criteria:

- Articles which study traffic lights and street crossing behaviour (e.g., signalised crosswalks), lighting-warning systems as well as focus on driver's experience.
- Studies where lighting was considered in combination with other aspects. For example, "challenging environments" (i.e., irregular surface and low lighting).
- Studies which were focused on subjects with disabilities (e.g., visually impaired subjects and glaucoma).

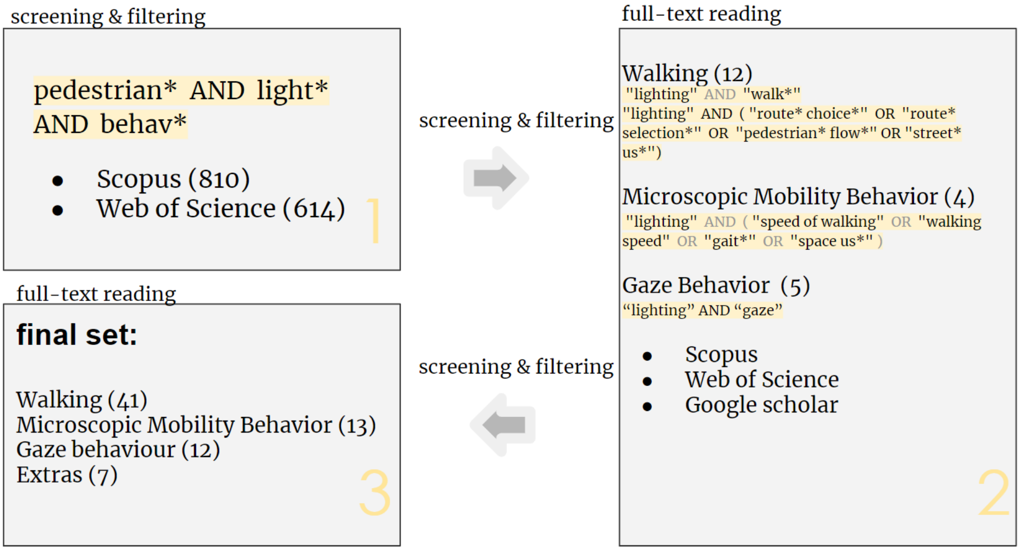

Fig. 1 – The flowchart of the literature search process

3. Results

3.1. Impacts of artificial lighting on pedestrians' behaviour

3.1.1. Walking. The perception of the built urban environment after dark dramatically differs from the perception under daylight. This fact, in its turn, leads to shifts in various urban experiences, activity levels and walking patterns of people. It was repeatedly found that outdoor lighting, being one of the components of the built environment, has a significant impact on different forms of physical activity after dark [3-20]. Firstly, it was statistically substantiated that ambient lighting conditions affect the number of people who walk or cycle [3-6]. It was found that conversely to daylight, darkness leads to notable reductions in pedestrians and cyclists, and that more people cycle and walk on cycle trails and footpaths after dark when they are artificially illuminated. In addition, the findings of study [6] demonstrated a significant reduction in footfalls after the clock change (i.e., when it dark outside) on 5 out of 6 sites on weekdays and half the sites at weekends. Secondly, the presence of good quality street lighting can increase the use of pedestrian streets and public spaces after dark by different user groups promoting walking and active lifestyle [7-11, 13-16, 18-20]. It is important to note that inadequate street lighting can also be considered as a walking and cycling barrier [12, 17, 21, 22]. For instance, the finding extracted from an interview: "For example, at a certain time of the day, a poor street lighting makes me take the bus instead of walking alone in the dark" depicted the relevance of lighting conditions in the selection of travel mode [21].

An artificial lighting environment has been found to affect the pattern of movement in terms of route choices. The study [23] explored the impact of altered visual perception after dark (i.e., in relation to the spatial configuration) on most frequently used routes and found the correlation between selected or most frequently used routes and illuminance values. In addition, according to the results of the study [24], people tended to avoid dark spots at night-time residential streets. The authors assumed that dark spaces, turning themselves into visual boundaries, can be largely attributed to decreased perceived safety and reassurance. Indeed, the results of studies [25-32] indicated that the reassurance of people (i.e., the feeling of confidence a pedestrian might gain from road lighting [33]) can be put in relation with outdoor lighting, and, moreover, can be considered as a key contributor to enhancing or limiting (e.g., compelled detours) walking at night-time. It is worth noting that blind spots, such as dark spaces between streetlights, under tree branches, and dark winding street corners, had a significant input to perceived safety, especially among female students [31]. In addition, the study [28] showed that urban greenery and street lighting must be explored and designed together, since their interaction influences perceived safety and impacts the walkability of the neighbourhood. Nevertheless, outdoor lighting can have an influence on walking also without a direct impact on perceived safety and reassurance. For instance, the walkability of an area can be related to visibility [34], perceived restorativeness [35, 36] or personal evaluations and preferences [31, 37, 38]. It is notable that the time spent in the environment can be altered by environmental features, including lighting [19].

It is important to highlight that when people are choosing a route, they also consider the quality of the lighting environment. The study [7] showed that the improved lighting schemes have a markable impact on the number of people using the streets. Moreover, there were several studies attempted to investigate how certain lighting variables influence walking patterns. It was found that among other factors average illuminance on the pavement affects pedestrian route taking decisions (i.e., pedestrians avoid routes with average illuminance of less than 5 lux and prefer routes with the average illuminance of 8 lux and above) [39]. Besides, the study [31] concluded that students' preference of the brightest lit route resulted in more foot traffic relative to other routes. Additionally, it was found that a decrease in the colour temperature of ambient lighting from 6500K to 3200K reduces the comfort level of pedestrians, as well as that colour temperature had the strongest influence on the choice of a route by pedestrians, compared with dimming [40]. Lastly, the use of targeted lighting design and visual cues such as projected light or chasing light-emitting diode (LED) lighting, had a potential to influence people's movement and behaviour [41, 42].

3.1.2. Microscopic mobility behaviour. Besides walking in a broad sense, lighting conditions can also impact on more precise parameters of human mobility, namely walking speed [42-48], gait characteristics [46, 47, 49, 50-53, 55] and use of the walkway space [42, 45, 54].

Suggesting that accelerated walking speed might indicate pedestrian discomfort, the authors of the study [43] showed that in the selected urban street a decrease in lighting does quicken pedestrian steps in comparison with the same street when well-lit or at daytime. In contrast, several laboratory experiments concluded that during walking a decrease in illumination leads to fall in a walking speed [44, 47] or a step rate [48]. The study [44] examined possible effects of dynamic lighting on walking. It was found that the participants walked significantly slower under dimmed than static lighting conditions, even after the illuminance had increased, and the larger were differences between the dimmed lighting levels and the full lighting, the longer was walking time. When comparing two different lighting conditions (high pressure sodium (HPS) and ceramic metal halide (CMH)), the authors of the study [45] reported that the mean speed was significantly slower under HPS lamps along the straight part of the path. Finally, the impact of targeted lighting design and visual cues on walking speed was also discussed [42, 44, 55]. It is worth noting that two studies [1, 54] did not find any walking speed changes with the change in lighting conditions.

There were several laboratory studies which found that the reduced illumination has an influence on various gait characteristics during walking which, for instance, can be indicators for slips, trips and fall accidents [46, 47, 49, 50-53]. For example, the lighting environment can affect such gait characteristics as stride length, stride time, double support time gait variability of stride length and stance time [49], stance phase ratio and toe clearance [47]. Moreover, changes in gait patterns under low illumination can be enhanced during obstacle avoidance tasks [51, 52] or when walking on stairs [41], as well as can be differently impacted among various user groups [46, 47, 53]. It was also found that reduced lighting conditions are significant on perceived risk of tripping [51, 52].

Outdoor lighting has also been found to affect the way people use a walkway space [42, 45, 54]. The authors of the study [54] observed pedestrian placement on pedestrian paths. Participants tended to vary their placement and change their path more with a fluorescent tube luminaire (FTL) light source than with a LED light source, which was explained by improved visual accessibility with the LED light sources. Moreover, the observations of pedestrian walking behaviour revealed a more centric walking path along the sidewalk under LED illumination, particularly with the optimised LED luminaire. Changes in passengers' behaviour such as an increase of the use of the left-hand side for descending, and a shift from the centre to the opposite side of the staircase after introduction of the targeted lights (i.e., handrail lighting on the stairway) were reported in the study [42]. In addition, it was noticed that the average path for lighting application with CMH was systematically closer to the centre line compared to application with HPS, although the difference, in absolute terms, was quite small [45].

3.1.3. Gaze behaviour. Lighting conditions can also affect a pedestrian's gaze behaviour while walking in terms of critical distances, viewing directions, the fixation number and fixation durations. It consequently impacts the way people execute their visual tasks such as object detection, visual identification, visual orientation and on the perception of the urban environments.

Pedestrians spent between 40% and 50% of their time looking at the footpath, but not all that time was spent on critical visual tasks [56]. Identification of other pedestrians and their emotions also appeared to be significant during walking [56-58]. It is notable that after dark the path was more likely to be fixated and other people less likely to be fixated compared with daylight [57]. The apparent importance of fixation on other pedestrians was also highlighted in the study [58]. Their results showed that the proportion of time that fixations were on pedestrians was 14%, the proportion of fixations at critical moments that were on pedestrians was 23%, and the probability of an approaching pedestrian being fixated at least once was 86%. In addition, the study [48] concluded that in the conditions of mesopic vision (i.e., 10 lux), older adults more often looked at the floor or the edge, especially without edge emphasis, which meant that higher levels of illuminance were associated with a decreased need for directing one's gaze towards the ground.

There were few studies analysing the distance and duration of fixations on other pedestrians and found a tendency to fixate at 15 m and for a duration of 500 ms [59, 60]. The judgement of other people's emotions from facial expressions can also be influenced by lighting conditions. For instance, to be assured in accurate identification of the facial expressions, the study [61] suggested requirements of a minimum luminance of the face of 0.1–1.0 cd/m^2 at 4 m distance, and a luminance above 1.0 cd/m^2 for identification at 10 m. Additionally, it was found that human's sense of where another person is looking can be biased by the lighting direction and eye glint, which also affects people's sense of gaze direction, varies with the lighting conditions [62].

Eye tracking records collected and discussed in the studies [57, 58, 63] suggested a tendency to peripherally detect 10 mm obstacles at approximately 3.4 m ahead under horizontal photopic illuminances of up to 0.9 lux. It is important to note that lighting requirements and a critical distance can vary, according to the scotopic/photopic ratio of the lighting and the age of the observer. In addition, it was reported that both the trial time and detection distance of older participants during a detection of an upcoming step were affected by light level, hence, their vulnerability may be reduced if a better lighting environment is provided [64].

Ultimately, relative luminance and saliency of a various scene areas may attract the visual attention of pedestrians. The study [65] found that fixations within 2° and 10° viewing angle were predominantly distributed in bright and significantly salient regions of the outdoor visual environment.

It is worth noting that background lighting conditions may impact spontaneous eyeblink activity, as well as that spontaneous eyeblink activity rate changes can occur when lighting levels suddenly increase [66].

3.2. Methods used to gather data about changes in pedestrian behaviour

3.2.1. Walking. There were both quantitative and qualitative approaches to study pedestrian behaviour which can relate to walking. Firstly, the total number of pedestrians who use the site can be recorded automatically by traffic counters [3, 4, 5] or by direct observation (e.g., a gait-counting method) [6, 7, 23, 40, 42, 67] for specific periods of time. Afterwards, count data collected for after dark conditions can be compared with daylight values by using the biannual daylight-saving clock changes approach

[3, 4, 6] or the whole-year approach [5]. To compare the usage of various artificially lit spaces or to evaluate changes after the lighting installation improvements, it is possible to implement real-time field observations [7, 23, 40, 67] or to analyse footage from fixed cameras [42]. These counts can be further used for the creation of the generative natural movement patterns [23]. Moreover, structured and semi-structured observations can be utilised to investigate stationary and transitory activities and measure their duration time [18], as well as people's movement and occupancy patterns [23, 42]. It is important to note that observed data should be carefully filled in protocols. A behavioural observation method might be combined with a lighting survey to allow researchers access to the context and meaning surrounding people's behaviour [39]. In addition, physical activity levels of the experiment participants can be assessed by accelerometery [11].

Another approach was to collect and analyse self-reported data through on-site and online pedestrian surveys [19, 32], interviews [8, 15, 22, 41] and environmental walks [28, 68]. Surveys were used for measuring physical activity [9, 10, 13] (e.g., the Youth Physical Activity Questionnaire [13]), walking and its characteristics (i.e., walking times, frequency, and duration) [16, 19, 26, 27] (e.g., the International Physical Activity Questionnaire [16]), and evaluations of behavioural intents and space perceptions in order to understand likely behaviour in particular sites [24, 29, 34, 38]. It is notable that a couple of studies used a real-time approach, according to which, participants filled in the surveys while walking along the sites with the help of a paper questionnaire [32] and a mobile phone application [30]. Interviews were used to gather qualitative data about perceived supports and barriers of physical activity [8], utilitarian walking [15] or walking routes [22], as well as unique knowledge from various groups of stakeholders or staff [41, 42]. Finally, there were several approaches of guided structured [28] and random [68] environmental walks. These approaches allowed researchers to gather subjective environmental evaluations, behavioural preferences, and ideas how to improve the neighbourhood in relation to walking.

3.2.2. Microscopic Mobility Behaviour. Walking speed was examined in both full-scale laboratory [1, 44] and field [43, 45, 54, 58] studies. It was measured as walking time a pedestrian took to cross an established distance [43] or the whole experimental site [1, 44]. The study [45] described a novel method based on Video Analysis of Pedestrian Movement (VAPM). The method includes adaptation of existing video technologies to measure actual microscopic movement (i.e., placement and speed). It was claimed that VAPM can be successfully combined with observer-based assessments. Pedestrian observations, in their turn, can also be performed to study walking speed (e.g., unexpected slowdown) [54]. Gait characteristics were studied in laboratory conditions with the help of infrared and reflective markers placed on anatomical landmarks of each participant and a tracking system such as an eight-camera motion analysis system [46, 47, 49, 50, 53]. Perceived risk of tripping was evaluated through self-reported protocols [51, 52]. Finally, the use of a walkway space can be assessed with such tools as direct observation in field studies [42, 54], analysis of recorded footage [42] or using VAMP [45].

3.2.3. Gaze behaviour. Studies related to gaze behaviour were predominantly implemented with the help of wearable eye-tracking systems. Among them, there were experiments carried out in controlled laboratory settings [48, 64], as well as studies which analysed the data obtained in real-world situations [56-60, 63, 65]. In these studies, participants were asked to wear eye-tracking devices (different manufacturer, but typical gaze position accuracy was between 0.5° and 1.0° and sampling frequency was around 25-30 Hz) and to walk along the defined routes, both freely and under a researcher's control. After that, measured eye movements were superimposed on a simultaneously recorded videotape to analyse gathered data and correlate it with aspects of the built environment or other people's presence. The critical distances within scenes can be estimated by relative size of reference objects in the field of view [60]. It is important to note that in most naturalistic studies, experiments were conducted during day and night [56-58, 65]. In addition, research questions connected with recognition of another person' intentions, emotional states or gaze directions can be done in laboratory settings using target images of actors [61] or faces produced with 3D graphical rendering software [62] showed on the screen under various lighting conditions or in digitally simulated lighting scenes.

4. Discussion and conclusion

This paper focuses on the changes in human behaviour whilst walking under an artificially lit outdoor environment. A systematic literature search was conducted using key words. During the search process three groups of pedestrians' behaviour (i.e., walking (including activity levels and walking patterns), microscopic mobility (including walking speed, gait characteristics and use of walkway space) and gaze behaviour) were identified. This division is a product of the authors' subjective view, and it was undertaken to ease the report process in describing existing knowledge on possible changes in pedestrian behaviour caused by various artificial lighting settings.

Several studies, which also can be associated with people' behaviour, were not included in the main body of the paper because they cannot be clearly assigned to the three identified groups. These studies were predominantly focused on various forms of interaction with other people and the environment. They covered such topics as impacts of light on personal space requirements [69], critical distances between pedestrians [70], approach and avoidance behaviour [71], de-escalation of aggression [72] and the issues connected with interaction between a human and urban environment through lighting means [73-75].

The current literature demonstrates a decent potential of lighting in influencing on various types of behaviour, as well as a great variety of research approaches and methods. Numerous findings described in the Chapter 3 show that the lighting environment has an impact on pedestrians' behaviour, depending on the ambient lighting condition (e.g., daytime or night-time), the presence of lighting posts, as well as the quantitative and qualitative aspects of particular lighting solutions. The absence of outdoor lighting or its poor quality seems to be a significant barrier to active lifestyle in a general city scale and can alter the pattern of pedestrian movement because of route and travel mode choices. To the date, articles which investigate how certain lighting variables influence the walking patterns are limited, although there were several findings suggesting that average illuminance on the pavement and the colour temperature of a light source tend to influence route choices [39, 40]. The reasons behind the changes in walking behaviour can be largely attributed to decreased perceived safety and reassurance, but also to perceived restorativeness, better visibility and subjective preferences. Moreover, the potential of targeted lighting design in issues of supporting pedestrians' behaviour was noticed [41, 42] and need to be further studied. An important aspect in relation to outdoor lighting along pedestrian paths could also be the possibility to walk smoothly and maintain a comfortable speed. It seems that reduced lighting conditions can influence the walking speed and the placement of a pedestrian on a walk path, decrease his or her gait's quality and increase the perceived risk of tripping. Besides the quantity of light, spectrum, dynamic routines, and targeted lighting design also have a potential to impact microscopic mobility behaviour. Lastly, it is important to note that lighting conditions may affect the way people execute their visual tasks such as object detection, visual identification, visual orientation and on the perception of the urban environments.

There were many different approaches in relation to gathering data about changes in pedestrian behaviour, including both quantitative and qualitative methods. Nevertheless, one of the current disadvantages for these methods is their limitation to a certain urban environment and difficulties in the collection of data in a city scale. In addition, it goes without saying that the development of a multi-tool, allowing gathering and correlating data on various types of changes in pedestrians' behaviour will reveal new opportunities in studying the impacts of lighting conditions.

It is worth discussing that the video-based analysis has a potential as a promising multi-tool for studying pedestrian behaviour in urban environments. First, this is due to the wide range of features currently offered by image-processing algorithms, computer vision and machine learning fields. There is a possibility to improve and further develop the approach suggested by M. Johansson et. al., where the authors adapted existing video technologies to measure microscopic movement, i.e., placement and speed [45]. For instance, in terms of analysing data, the VAPM method can be enriched with the analysis related to gaze behaviour and microscopic mobility behaviour, namely by capturing gaze directions with head posture estimation [76] and by measuring gait features with extracting body parts from the image [77]. Other possible improvements can relate to capturing facial features and/or expressions [78], action recognition [79] and crowd behaviour [55] analysis. Secondly, the method has a decent prospect because of steady integration of video cameras in our daily lives through video security surveillance and smart city applications. This fact gives the opportunity for researchers to work with a great amount of video data, supporting clear and stable conclusions about impacts of lighting environments. Finally, when the impacts and correlations between outdoor lighting and human behaviour will be better studied, it would be possible to control lighting installations based on real-world images captured from video cameras. Nevertheless, to date, the ethical issues corresponded with an operation of surveillance data represent a major barrier in a detailed assessment of pedestrian behaviour.

Another promising approach to study walking patterns of pedestrians is applying an online public participation geographic information system (PPGIS) methodology [80]. GIS-based measures were already used in previous research studies related to built environment and lighting [10, 15, 23], digitising the positions of street lighting posts. Hypothetically it is also possible to correlate the physical locations of lighting posts with related lighting sources' characteristics or even show the lighting spatial distribution of the area. Public participation (PP) helps to map the user's knowledge and experience to different urban places, making city-scale participation possible. The correlation between HardGIS and SoftGIS knowledge layers reveals the possibility to study human behaviour and experiences in relation to the physical environment. The approach has a means to potentially reach a larger number of participants than traditional methods and to include various groups of people and languages. The data collected through PPGIS may be subjected to scientific standards of data quality [81], but generally can be served for both research and planning/design objectives. For instance, N. Davoudian and A. Mansouri conducted an interview where respondents were asked to indicate a walking route they usually take during the day on a map of the area [22, 39]. Afterwards they were asked whether they would take the same route at night for the same purpose as daytime or describe the reasons why an alternative route will be chosen. It goes without saying that this methodology can be successfully digitised and applied on a bigger scale.

References

[1] Rahm J and Johansson M 2018 Assessing the pedestrian response to urban outdoor lighting: a full-scale laboratory study PLoS ONE 13(10):e0204638
[2] Rahm, J., 2019. Urban outdoor lighting: Pedestrian perception, evaluation and behaviour in the lit environment. Ph. D. Lund University
[3] Fotios S and Robins C J 2022 Effect of ambient light on the number of motorized vehicles, cyclists, and pedestrians Transport Res. Record: J. of the Transportation Res. Board 2676 issue: 2 593-605
[4] Uttley J and Fotios S 2017 Using the daylight savings clock change to show ambient light conditions significantly influence active travel J. of Env. Psych. 53 1-10
[5] Fotios S, Uttley J and Fox S 2017 A whole-year approach showing that ambient light level influences walking and cycling Lighting Res. & Technology 51 issue: 1 55-64
[6] Unwin J, Symonds P and Laike T 2017 Proc. of the Lux European Lighting Conf. - Lighting for Modern Society, ed M B Kobav et al (Ljubljana) pp 245-250
[7] Painter K 1996 The influence of street lighting improvements on crime, fear and pedestrian street use, after dark Landscape and Urban Planning 35 issue 2-3 193-201
[8] Addy C L, Wilson D K, Kirtland K A, Ainsworth B E, Sharpe P and Kimsey D 2004 The American J. of Public Health 94(3) 440-443
[9] Lee C and A V Moudon 2008 Neighbourhood design and physical activity Building Res. & Information 36 issue 5 395-411
[10] Edwards N, Hooper P, Knuiman M, Foster S and Giles-Corti B 2015 Association between park

features and adolescent park use for physical activity Int. J. of Behavioral Nutrition and Phys. Activity 12, 21
[11] Jago R, Baranowski T, Zakeri I and Harris M 2005 Observed environmental features and the physical activity of adolescent males American J. of Preventive Med. 29, issue 2 98-104
[12] Bonaccorsi G, Manzi F, Del Riccio M, Setola N, Naldi E, Milani C, Giorgetti D, Dellisanti C and Lorini C 2020 Impact of the built Environment and the neighborhood in promoting the physical activity and the healty aging in older people: an umbrella review Int. J. Env. Res. Public Health 17(17)
[13] Hermosillo-Gallardo M E, Sebire S J and Jago R 2020 Perception of safety and its associaion with physical activity in adolescents in Mexico American J. of Preventive Med. 58, issue 5, 748-755
[14] Nabipour M, Nasseri S H and Saber E T 2021 Comparison and evaluation of built environment factors for developing pedestrian urban travels Fuzzy Information and Eng. 13, issue 4 505-521
[15] Lee C, Lee C, Stewart O T, Carlos H A, Adachi-Mejia A, Berke E M and Doescher M P 2021 Neighborhood environments and utilitarian walking among older vs. younger rural adults Frontiers in Public Health 9:634751
[16] Corseuil Giehl M E, Hallal P C, Brownson R C and d'Orsi E 2017 Exploring associations between percieved measures of the environment and walking among older adults J. of Aging and Health 29 issue: 1 45-67
[17] Rydenstam T, Fell T, Geleta Buli B, King A C and Bälter K 2020 Using citizen science to understand the prerequisites for physical activity among adolescents in low socioeconomic status neighborhoods - the NESLA study Health & Place 65 (2020) 102387
[18] Al Odat S M and Al Kurdi N 2020 Lively streets: the role of streetscape elements in improving the experience of commercial street users in Amman, Jordan J. of Settlements and Spatial Planning 12, no. 1 1-12
[19] Akpinar A 2016 Factors influencing the use of urban greenways: a case study of Aydin, Turkey Urban Forestry & Urban Greening 16 123-131
[20] Mateo-Babiano I 2016 Pedestrian's needs matter: examining Manila's walking environment Transport Policy 45 107-115
[21] Ferrer S and Ruiz T 2018 The impact of the built environment on the decision to walk for short trips: evidence from two Spanish cities Transport Policy 67 110-120
[22] Davoudian N and Mansouri A A 2017 Int. Conf. on Env. Psych. Book of Abstracts (A Coruna) p 63-64
[23] Dwimirnani P, Karimi K and Palaiologou F 2017 Proc. of 11th Space Syntax Symp. (Lisbon) #129
[24] Komatsu Y, Egoshi M, Ikeda T and Tamada T 2011 The distribution and effects of dark spots at night-time residental streets J. of Env. Engineering (Transactions of AIJ) 76 Issue 666 641-647
[25] Ferrer S, Ruiz T and Mars L 2015 A qualitive study on therole of the built environment for short walking trips Transport Res. Part F: Traffic Psych. and Behaviour 33 141-160
[26] Park Y and Garcia M 2020 Pedestrian safety perception and urban street settings Int. J. of Sustainable Transportation 14, No. 11 860-871
[27] Lee J S, Park S and Jung S 2016 Effect of crime prevention through environmental design (CPTED) measures on active living and fear of crime Sustainability 2016,8(9), 872
[28] Rahm J, Sternudd C and Johanson M 2021 "In the evening , I don't walk in the park": the interplay between street lighting and greenery in perceived safety Urban Design Int. 26 42-52
[29] Kobayashi S, Nakamura Y and Hosoya S 2017 A low illuminance lighting arrangement to enchance the natural experience in a resort area J. of Illuminating Engineering Institute of Japan 101 issue 2 82-87
[30] Hughes N, Ryan B, Hallewell M, Coad N, Grant A, Parrot N, Roberts S and Thompson K 2020

Identifying new concepts for innovative lighting-based interventions to influence movement and behaviours in train station Lighting Res. & Technology 52 issue: 8 976-990
[31] An H, Chung H and Chang J 2020 Gendered perception of night-time walking safety in urban-rural campus town - focusing on the CPTED project and street lighting J. of the Architectural Institute of Korea 36 Issue 12 77-87
[32] Mattoni B, Burattini C, Bisegna F and Fotios S 2017 Conf. Proc. 2017 IEEE Int. Conf. on Env. and Electrical Eng. and 2017 IEEE Industrial and Commercial Power Systems Europe (EEEIC / I&CPS Europe) (Milan) p 1-5
[33] Fotios S, Unwin J and Farrall S 2015 Road lighting and pedestrian reassurance after dark: A review Lighting Research and Technology 47 issue: 4 449-469
[34] Prihatiningrum A, Ramawangsa P A and Seftyarizki D 2021 Artificial lithtin strategies on campus pedestrian path in increasing the safety of walking in night (case study: university of Bengkulu) IOP Conf. Series: Earth and Env. Sci. 738 012042
[35] Nikunen H, Puolakka M, Rantakallio A, Korpela K and Halonen L 2013 Perceived restorativenes and walkway lighting in near-home environments Lighting Res. & Technology 36 issue: 3 308-328
[36] Kobayashi S, Nakamura Y and Hosoya S 2017 A low illuminance lighting arrangement to enchance the natural experience in a resort area J. of Illuminating Engineering Institute of Japan 101 issue 2 82-87
[37] Nasar J L and Bokharaei S 2017 Lighting modes and their effects on impressions of public squares J.of Env. Psych. 49 96-105
[38] Casciani D 2020 A virtual experience of the human-scale urban lightscape The Human and Social Dimensions of Urban Lightscapes (Springer Cham) pp 79-97
[39] Davoudian N and Mansouri A A 2016 Proc. of CIE 2016 Lighting Quality and Energy Efficiency (Melbourne) pp 588-595
[40] Bystryantseva N V, Antonov R A and Balaev A F 2020 Assessment of the impact of street lighting on usage activity of pedestrian traffic spaces on the example of the square in Saint Petersburg IOP Conf. Series: Materials Sci. and Engineering 962 042001
[41] Hughes N, Ryan B, Hallewell M, Coad N, Grant A, Parrot N, Roberts S and Thompson K 2020 Identifying new concepts for innovative lighting-based interventions to influence movement and behaviours in train station Lighting Res. & Technology 52 issue: 8 976-990
[42] Ryan B, Hallewell M, Hughes N, Coad N, Eliseu J, Lira M, Grant A, Parrot N and Thompson K 2021 Field testing two innovative lighting interventions to influence waitning behaviours and movements on stairways in train stations Preprint doi.org/10.1177/14771535211016811
[43] Donker S F, Kruisheer J and Kooi F 2011 Env. 2.0: the 9th Biennial Conf. on Env. Psych. ed A Haans et al (Eindhoven) pp 125-126
[44] Pedersen E and Johansson M 2018 Dynamic pedestrian lighting: effects on walking speed, legibility and environmental perception Lighting Res. & Technology 50 issue: 4 522-536
[45] Johansson M, Laureshyn A and Nilsson M 2020 Video analysis of pedestrian movement (VAPM) under different lighting conditions - method exploration Energies 2020,13,4141
[46] Berard J R and Ann Vallis L 2006 Characteristics of single and double obstacle avoidance strategies: a comparison between adults and children Experimental Brain Res. 175 21-31
[47] Choi J-S, Kang D-W, Shin Y-H and Tack G-R 2014 Differences in gait pattern between the eldery and the young during level walking under low illumination Acta Bioengineering and Biomechanics 16, nr 1 3-9
[48] Itoh N 2006 Visual guidance of walking: effects of illumination level and edge emphasis Gerontechnology 5, No. 4 246-252
[49] Huang C-K, Chien J-H and Siu K-C 2017 The reduced lighting environment impacts gait characteristics during walking Int. J. of Industrial Ergonomics 61 126-130
[50] Cho S-Y, Ryu Y-U, Dong Je H, Jeong J H, Ma S-Y and Kim H-D 2013 Effects of illumination on toe clearence and gait parameters of older adults when stepping over an obstacle: a pilot

study J. of Phys. Therapy Sci. 25 Issue 3 229-232
[51] Li K W, Chen Y, Li N, Duan T and Zou F 2020 Assessment of risk of tripping before and after crossing obstacles under dimmed lighting conditions Work 66, no 3 551-559
[52] Li K W, Chen Y, Zou F, Li N and Duan T 2019 Perception of risk of tripping under lighting and obstacle conditions Human Factors and Ergonomics in Manufacturing & Service Industries 29, Issue 6 529-536
[53] Hamel K A, Okita N, Higginson J S and Cavanagh P R 2005 Foot clearance during stair descent : effects of age and illumination Gait & Posture 21, Issue 2 135-140
[54] Markvica K, Richter G and Lenz G 2019 Impact of urban street lighting on road users' perception of public space and mobility behavior Building and Env. 154 32-43
[55] Haans A, Corbetta A, Kumar P and Toschi F 2017 Int. Conf. on Env. Psych. Book of Abstracts (A Coruna) p 219
[56] Davoudian N and Raynham P 2012 What do pedestrians look at night? Lighting Res. & Technology 44 issue: 4 438-448
[57] Fotios S, Uttley J, Cheal C and Hara N 2015 Using eye-tracking to identify pedestrians' critical visual tasks, part 1. Dual task approach Lighting Res. & Technology 47 issue: 2 133-148
[58] Fotios S, Uttley J and Yang B 2015 Using eye-tracking to identify pedestrians' critical visual tasks. Part 2. Fixation on pedestrians Lighting Res. & Technology 47 issue: 2 149-160
[59] Fotios S, Uttley J and Fox S 2018 Exploring the nature of visual fixations on other pedestrians Lighting Res. & Technology 50 issue: 4 511-521
[60] Fotios S, Yang B and Uttley J 2015 Observing other pedestrians: investigating the typical distance and duration of fixation Lighting Res. & Technology 47 issue: 5 548-564
[61] Fotios S, Yang B and Cheal C 2015 Effects of outdoor lighting on judgements of emotion and gaze direction Lighting Res. & Technology 47 issue: 3 301-315
[62] Palmer C J, Otsuka Y and Clifford C W G 2020 A sparkle in the eye: illumination cues and lightness constancy in the perception of eye contact Cognition 205(2020)104419
[63] Fotios S and Uttley J 2018 Illuminance required to detect a pavement obstacle of critical size Light Res. & Technology 50 issue: 3 390-404
[64] Cheng T-J, Yang B, Holloway C and Tyler N 2018 Effect of environmental factors on how older pedestrians detect an upcoming step Lighting Res. & Technology 50 issue: 3 405-415
[65] Jiand X, Li J and Yang B 2021 Luminance and saliency have impact on pedestrians' fixation distribution during natural walking: evidence from mobile eye-tracker Lighting Res. & Technology 53 issue: 4 359-372
[66] Doughty M J 2013 Effects of background lighting and retinal illuminance on spontaneous eyeblink activity of human subjects in primary eye gaze Eye & Contact Lens: Sci. & Clinical Practice 39 - Issue 2 138-146
[67] Rahm J and Johansson M 2021 Assessment of outdoor lighting: methods for capturing the pedestrian experience in the field Energies 2021,14(13),4005
[68] Patching G R, Rahm J, Jansson M and Johansson M 2017 A new method of random environmental walking for assessing behavioral preferences for different lighting applications Frontiers in Psych. 8:345
[69] Adams L and Zuckerman D 1991 The effect of lighting conditions on personal space requirements The J. of General Psych. 118 - Issue 4 335-340
[70] Berghuis W J H, den Hartog I, Romijn A R and Haans A 2014 Proc. Experiencing Light 2014 ed Y A W de Kort et al (Eindhoven) p 133
[71] Veenstra L and Koole S L 2018 Disarming darkness: effects of ambient lighting on approach motivation and state anger among people with varying trait anger J.of Env. Psych. 60 34-40
[72] de Kort Y A W, Ijsselsteijn W A, Haans A, Lakens D, Kalinauskaite I and Schietecat A 2014 Proc. Experiencing Light 2014 ed Y A W de Kort et al (Eindhoven) pp 94-97
[73] Pihlajaniemi H and Luusua A 2020 Playful and playable lighting in smart cities: towards a holistic framework of design Making Smart Cities More Playable ed A Nijholt (Springer) pp 149-177

IOP Conf. Series: Earth and Environmental Science 1099 (2022) 012007 doi:10.1088/1755-1315/1099/1/012007

[74] Poulsen E, Morrison A, Jorgen Andersen H and Jensen O B 2013 Mobile HCI '13: 15th Int. Conf. on Human-Computer Interaction with Mobile Devices and Services (Munich) pp 217-226
[75] Casciani D 2014 Urban social lighting. Exploring the social dimension of urban lighting for more sustainable urba nightscapes (Milano: Politecnico di Milano)
[76] Murphy-Chutorian E and Trivedi M 2009 Head Pose Estimation in Computer Vision: A Survey body parts. IEEE Transactions on Pattern Analysis and Machine Intelligence. 31 pp 607-626
[77] Kim W, Kim Y 2018 Human Body Model using Multiple Depth Camera for Gait Analysis Action. International Conference on Software Engineering, Artificial Intelligence, Networking and Parallel/Distributed Computing (SNPD). pp 70-75
[78] Zadobrischi E et al 2020 Detection of Emotional States Through the Facial Expressions of Drivers Embedded in a Portable System Dedicated to Vehicles. 28th Telecommunications Forum (TELFOR). pp 1-4
[79] Dawar N and Kehtarnavaz N 2017 Continuous detection and recognition of actions of interest among actions of non-interest using a depth camera EEE International Conference on Image Processing (ICIP). pp 4227-4231
[80] Brown G and Kyttä M 2014 Key issues and research priorities for public participation GIS (PPGIS): a synthesis based on empirical research Applied Geography 46 122-136
[81] Fagerholm N, Raymond C M, Stahl Olafsson A, Brown G, Rinne T, Hasanzadeh K, Broberg A and Kyttä M 2021 A methodological framework for analysis of participatory mapping data in research, planning and management Int. J. of Geographical Information Sci. 35 -Issue 9 1848-75