Journal of Transport & Health 16 (2020) 100797

Contents lists available at ScienceDirect

Journal of Transport & Health

journal homepage: http://www.elsevier.com/locate/jth

How does walkability change relate to walking behavior change? Effects of a street improvement in pedestrian volumes and walking experience

Paulo Cambra *, Filipe Moura

CERIS, Instituto Superior Técnico, Universidade de Lisboa, Av.Rovisco Pais 1, 1049-001, Lisboa, Portugal

ARTICLE INFO

Keywords:
Before-after
Street improvement
Walkability
Walking
Walking behaviour

ABSTRACT

Introduction: Promoting walking has become a policy concern in the public health and transport fields. Street improvement interventions aimed at increasing walking require an assessment of their effectiveness in influencing walking behaviour. There is a current gap in understanding how the magnitude of a change in walkability relates to a change in pedestrian volumes and walking experience.

Methods: This study reports a before-after analysis of the effects of a built environment intervention in the walking behaviour of adults in Lisbon, Portugal. The Eixo Central project aimed at improving walking conditions by changing physical factors in three sites – two avenues connected by a plaza. Each site had particular and distinct improvement approaches. We performed a before-after walkability assessment of the intervention area using a validated methodology, a longitudinal analysis of the pedestrian volumes in the intervention sites and control areas, and a quasi-longitudinal survey on the walking experience of residents, workers and frequent visitors of the area.

Results: The Eixo Central project improved overall walking conditions. Walkability scores point to changes of different magnitude in the walkability of each of the three sites. The results show a significant change in the sites' pedestrian volumes and walking experience between baseline and follow up, and a non-significant change in the control areas' pedestrian volumes in the same period. We found higher walkability changes to be associated with a higher increase in pedestrian volumes and to a higher positive influence in walking experience. Conversely, smaller scale walkability changes were associated with a less expressive change in pedestrian volumes and walking experience.

Conclusions: The results suggest that the scale of walkability change of environmental interventions is a significant factor in influencing walking behaviour. In this sense, smaller-scale interventions may be effective in improving the walking experience but not as effective in increasing walking activity.

1. Introduction

The preponderance of sedentary lifestyles and car-dependence have raised a concern on both health and transportation fields (Lee

* Corresponding author.
E-mail addresses: Paulo.cambra@tecnico.ulisboa.pt (P. Cambra), fmoura@tecnico.ulisboa.pt (F. Moura).

https://doi.org/10.1016/j.jth.2019.100797
Received 10 May 2019; Received in revised form 19 November 2019; Accepted 21 November 2019
Available online 25 November 2019

and Moudon, 2004) The promotion of active travel has been recognized as a mean to achieve essential exercise. Walking, in particular, has been found to provide a broad influence on public health (Frank et al., 2006) given the associated physical and psychological benefits that can be incorporated for free into everyday life (Ogilvie et al., 2007). The role of built environment in facilitating or hindering walking has been well established and reviewed in walkability research drawing from the fields of public health, transportation and urban planning (Forsyth and Krizek, 2010; Ewing et al., 2016). Following its rationale, it can be hypothesized that improving the walking environment can positively influence walking behaviour, increasing pedestrian activity (e.g. the number of trips, minutes of walking, modal change). Today, many cities aim in improving their environmental conditions in order to increase residents' health and wellbeing, driving investments to interventions that reshape the urban space into a more walking friendly environment (Ferreira et al., 2016). Such investments, often involving high-costs, are made on the premise that a better environment will have effects in walking behaviour, without reliable evidence of their effectiveness (Van de Coevering et al., 2015; Keall et al., 2015). Various studies support the hypothesis that improving the walking environment at the street level can positively influence walking behaviour. If on one hand it has been said that "micro-design elements are too 'micro' to exert any fundamental influences on travel behaviour" (Cervero and Kockelman, 1997), on the other hand evidence on the influence that such micro-scale elements can exert in walking, adding to the attractiveness of walking environments, has been put forward (Foltête and Piombini, 2007; Adkins et al., 2012; Ewing et al., 2016; Cain et al., 2017).

Despite the considerable body of research related to the environmental factors that enable walking, few studies have addressed the assessment of before-after walking behaviour in relation to a built environment intervention. These have focused in two types of interventions: the provision of new walking infrastructure and improvements to the pedestrian environment. Focusing on the provision of new walking infrastructure, Panter et al. (2016) studied the effects of the opening of the Cambridgeshire Guided Busway (Cambridge, United Kingdom) which comprised a new bus network, and a 22 km traffic-free walking and cycling route. Their 3 year study found no evidence of effects on time spent walking for transportation or recreation. Contrastingly, Pazin et al. (2016) reported a higher increase in leisure time walking (around 30 min/week) of adults following a new walking route along the seashore of the city of Florianópolis (Brazil). The new 2.3 km long walking and cycling route was said to bring a pleasant and traffic safe place for leisure along the shore. Regarding environmental improvements, Sun et al. (2014) followed the effects of improved pedestrian connections and the addition of bus stations in a Hong Kong University campus finding an increase in the average distance walked by students. Jensen et al. (2017) addressed two street renovations in Salt Lake City (U.S.A.) which involved the addition of a new light rail line and stops. They observed changes in pedestrian volumes in the two street interventions and in two control streets finding an increase of pedestrians' use in the renovated environments but not a significant change on the control locations. Jung et al. (2017) conducted a comprehensive study on the effects of a large street environment program on the pedestrian volume and satisfaction in Seoul (Seoul's Design Street Project, South Korea). The Design Street project comprised 23 retrofit projects targeting sidewalk and public space improvements. They examined the impact of the physical improvements in the pedestrian volumes and satisfaction observing 28 retrofitted locations (treatment group) and 218 control locations. They found a general increase in the pedestrian volumes of treatment group location but also an increase in the pedestrian volume of the control areas, hence no evidence was found that the environmental intervention attracted more pedestrians. On the other hand, pedestrian satisfaction increased only the streets of the Design Project whilst decreasing in the control locations, showing evidence of a positive influence of environmental improvements in pedestrian satisfaction.

The evidence found in existing studies is therefore mixed. Some interventions seem to have been more successful than others in influencing walking behaviour. However the outcomes are not clearly comparable. Not only the analysis timespan varies from a few months to 3 years, but also the dependent variable -walking behaviour-is addressed in various ways: time spent walking for transportation (Panter et al., 2016); time spent walking for leisure (Pazin et al., 2016); distance walked (Sun et al., 2014); pedestrian counts (Jensen et al., 2017; Jung et al., 2017) and pedestrian satisfaction (Jung et al., 2017).

Regarding the latter, walking experience and the influence of experience in triggering walking behaviour have been somehow overlooked in travel behaviour research (Ameli et al., 2015; Dadpour et al., 2016). Experiential qualities and satisfaction are factors believed to trigger and sustain behaviour change (Isaacs, 2010; Ettema et al., 2011; Kim et al., 2014; Bornioli et al., 2018), whose importance in shaping walking behaviour has been long recognized in the urban planning field (e.g. Lynch, 1960; Gehl, 1987, 2010; Jacobs, 1993).

Also, while previous studies have reported on walking behaviour change there is still a gap in reporting the extent of the environmental changes in relation to behavioural change. Few studies have provided a comprehensive analysis of the context of the intervention, namely in terms of before-after walkability levels. This poses a relevant implication: while the extent of effects in walking behaviour may be related to the magnitude of the walkability change, in turn such magnitude (i.e. size and importance) is not addressed, possibly conducing to the mixed results found in the literature.

Numerous methods and tools for walkability measurement have been proposed, spanning to the health, transportation, and urban planning fields (see for instance the reviews of Gebel et al., 2007; Holle et al., 2012; Asadi-Shekari et al., 2013; Lee and Talen, 2014; Vale et al., 2015; Wang and Yang, 2019). Some of these methods have been recognized and adopted by researchers in cross sectional studies but only limited applications are found in longitudinal street improvement studies (e.g. Jensen et al., 2017). This kind of environmental change comprises mostly micro factors, setting the scale of analysis to street level walkability. Established walkability measurement methods often work on larger scale analysis, such as the neighbourhood (Saelens and Sallis, 2002; Frank et al., 2005; Leslie et al., 2007). Others, like Walk Score ™, use gravity models to assess activities within walking reach disregarding environmental factors (Hall and Ram, 2018). Walkability measures focusing on micro scale modifiable elements are somewhat less well established, probably due to a more complex operationalization: street audits are usually required to collect street level data, being time consuming and prone to subjectivity.

Recent development proposals aimed to improve the feasibility of micro scale walkability measures. For instance Cain et al. (2017) worked on the Microscale Audit for Pedestrian Streetscapes (MAPS) scale (Millstein et al., 2013) in order to reduce the number of audited items and associated burden from 120 to 54. Later, the authors proposed an "international version" of this tool, highlighting the importance of addressing a wider diversity of environmental factors found in different countries (Cain et al., 2018). In their recent review, Wang and Yang (2019) found that the majority of walkability measurement tools are still originating from the USA, Australia and Canada, despite a growing number of studies adapting walkability measures to local settings. Within the context of the present study, Lisbon (Portugal), Moura et al. (2017) have proposed a walkability assessment framework addressing local pedestrian concerns suitable for the longitudinal analysis of micro scale walkability. Moreover previous studies have validated the tool's walkability measures against one of the variables of interest, finding a significant and positive association between walkability scores and pedestrian volumes (Cambra et al., 2017). Hence, this framework was selected to score the before-after walkability levels. In brief, the IAAPE (Indicators of Accessibility and Attractiveness of Pedestrian Environments) walkability framework combines street auditing with GIS analysis on a robust pedestrian network, providing a walkability score at the segment/block level.

This study aims to provide a systematic before-after evaluation of a street improvement intervention, assessing it in relation to walkability change, change in pedestrian volumes and change in walking experience. To the best of our knowledge no previous studies have provided a systematic evaluation of these three factors combined. One major contribution of this study is to fill this gap, shedding light on the understanding why some interventions are successful in influencing walking behaviour and others are not. For this we conducted a before-after study within the context of a major street retrofitting in Lisbon, collecting baseline and follow up data on walkability and pedestrian flows and collecting a survey at follow up.

2. Methods

A large scale street improvement project was recently implemented in Lisbon, Portugal, presenting an opportunity to conduct a

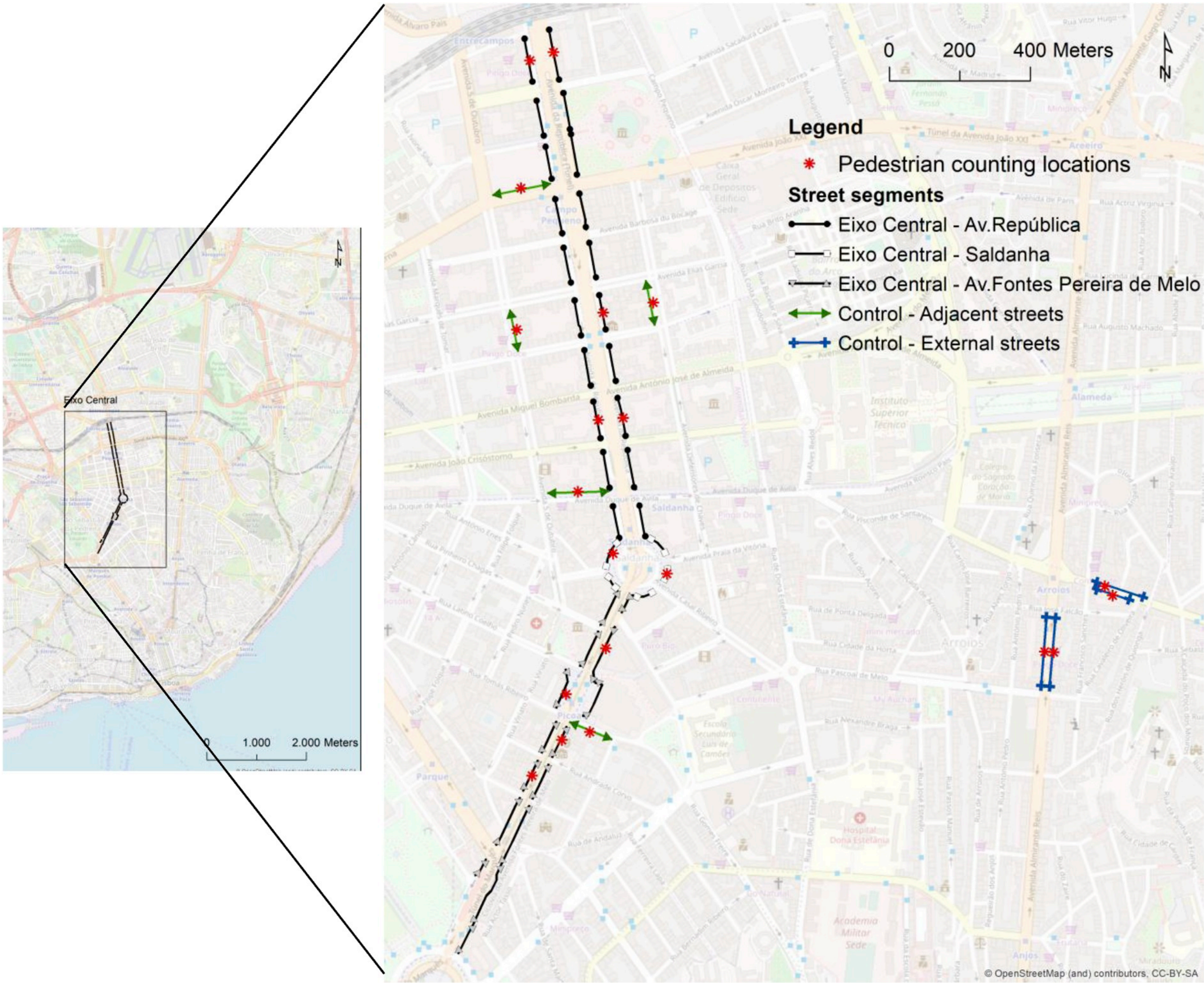

Fig. 1. Eixo central, adjacent control and external control locations.

quasi-experimental before-after assessment on the effects of enhanced walkability in pedestrian volumes and walking experience. In particular, the before–after study of pedestrian volumes in relation to walkability change followed a quasi-experimental design whilst a quasi-longitudinal survey addressed the before-after assessment of walking experience.

2.1. Study design

The use of quasi-experiments has been suggested to enable firmer causal inferences than cross-sectional observations in transport behaviour research. (Krizek et al., 2009; Chapman et al., 2014). Quasi-experimental designs do not randomly assign control units (Shadish et al., 2002), but often assign treatment and control groups at a larger scale, such as neighbourhoods (Van de Coevering et al., 2015). Such control areas should match the characteristics of the area where the intervention takes place, or, in practical terms, they should be at least "broadly comparable" as each area of a city is unique to some extent (Ogilvie et al., 2006). We considered two control locations for the analysis of pedestrian volumes: the "adjacent" area and the "external" area (Fig. 1). The "adjacent" area comprised all parallel and crossing street segments, similar to a 150 m buffer around the Eixo Central. The "external" control area comprised two major streets (Av.Almirante Reis and R.Morais Soares) linked by a round plaza –Praça do Chile, with an average pedestrian volume similar to the one of Eixo Central. The nodes of the "external" area and of the Eixo Central area are located at a straight line distance of 900 m, which correspond to a walking distance of 1.2 km and 16 min (using Google Maps online routing service). We considered the "external" area to be sufficiently similar in terms of urban characteristics to the Eixo Central but also to be sufficiently far apart. Likewise we considered the "adjacent" control area to be comparable in terms of population and urban characteristics.

Walking experience was addressed using a retrospective survey, following a quasi-longitudinal design. This involves asking respondents to recall information on a number of characteristics from a previous point in time as well as for the current time. Retrospective surveys, being prone to memory errors and other inaccuracies are considered less reliable than longitudinal studies. However, the use of retrospective surveys could be considered when longitudinal studies are not feasible (Behrens et al., 2010; Milakis and van Wee, 2018). This is often the case in studies addressing travel behaviour change following environmental change (Handy et al., 2005; Cao et al., 2007; Vale, 2013).

2.2. Walkability assessment

Walkability was assessed using the IAAPE framework proposed by Moura et al. (2017). This method addresses micro-level walkability (i.e. street-level), providing 8 distinct specifications for assessing walkability according to 2 walking purposes (utilitarian and recreational) and 4 pedestrian groups (adults, children, seniors, mobility impaired). A walkability score between 0 and 100 is obtained by means of a weight function whose inputs are 7 key-concerns: connectivity; convenience; comfort; conviviality; conspicuousness; coexistence and commitment. The 7 key-concerns are evaluated using a set of indicators. According to Moura et al. (2017) each model specification provides specific measurement indicators and weights. The indicators can be of qualitative or quantitative nature, being operationalized using street audits and GIS analysis. Prior to the calculation of the walkability score all indicators are normalized with value functions that convert qualitative and quantitative scales into a 0–100 range of values.

In the present case, the specification for adults and utilitarian walking was selected: the intervention occurred in an area that could be considered to be a central business district and the majority of pedestrians using the area fit into the adult group. The walkability score for each street segment is calculated using the following equation:

$$\textit{Walkability Score [Adults;Utilitarian]} = 0.17 * \textit{Connectivity} + 0.06 * \textit{Convenience} + 0.17*\textit{Comfort} + 0.17*\textit{Conviviality} + 0.11*\textit{Conspicuousness} + 0.22*\textit{Coexistence} + 0.11*\textit{Commitment}$$

Regarding this specification, the indicator for connectivity is "Pedestrian infrastructure continuity", convenience is related to "land use diversity", comfort to "pavement quality", conviviality to "service hours of activities"; conspicuousness to the "presence of distinctive landmarks"; coexistence to "traffic safety at pedestrian crossings"; and commitment to "the enforcement of pedestrian accessibility regulation". Within these factors, it is expected some to be less respondent to change within a consolidated mixed-use urban area (e.g. network structure, land use diversity) whilst others can undergo significant change following a street retrofitting (e.g. pavement quality, crossing safety). The model was operationalized as follows:

- Connectivity: the pedestrian infrastructure continuity indicator was measured using a topological sinuosity indicator, i.e. the ratio between least-cost topological length and the Euclidean distance between census block centroids. ESRI ArcMap 10 Network Analyst package was used to perform the calculation over a digitized pedestrian network. The digital pedestrian network, obtained by manual digitization, categorizes each topological component of the pedestrian network (Cambra et al., 2019).
- Convenience: Land use diversity was measured by field observation in a 0 to 4 scale, observing the presence of up to 4 classes of land uses – residential; commercial; services and public facilities – within a street segment, classifying as 0 a vacant lot.
- Comfort: Pavement quality was measured qualitatively on site, in a 1–5 scale, ranging from presence of holes, irregular pavement (1) to smooth and regular pavement (5), combined with the assessment of tripping hazards (dichotomous 0/1).
- Conviviality: The Service hours indicator was measured by a dummy variable where 1 denoted any activities located in the street segment working after 19 pm (e.g. cafes, shops).

- Conspicuousness The existence of landmarks was measured on site, in a 0–2 scale where 0 corresponded to inexistent or visible landmarks (e.g. monuments, distinctive buildings or shops, squares, etc.); 1 if landmarks could be seen from the centre of the street segment and 2 if landmarks were located at the street segment.
- Coexistence: Traffic safety at pedestrian crossings was obtained by a combined assessment of crossing configuration (number of lanes and traffic directions); crossing visibility and potential crossing conflicts (number of car movements that can hit a crossing pedestrian)
- Commitment: Enforcement of pedestrian regulations/law enforcement was calculated by the ratio of street segments complying with the local pedestrian accessibility regulations within the street segment's census block.

2.3. Settings

The Eixo Central project was planned in the scope of a public participation process in 2012, where Lisbon residents selected the creation of an accessible pedestrian route between two important transportation nodes, Entrecampos, and Marquês de Pombal. Despite the existence of specific regulation on pedestrian accessibility (Disability act – Portuguese Decree Law 163/2006) to enforce accessible conditions to all pedestrians, most of Lisbon's pedestrian network still inflicts accessibility constraints to impaired citizens.

The development of the project brought out a set of more extensive changes to the environment than the creation of an accessible pedestrian route. The Municipality of Lisbon laid as bold objectives for the intervention to provide "more green spaces, more sidewalks, more sitting out, more people, and fewer cars". The project involved the retrofitting of two of the city's main avenues (Avenida

Fig. 2. Av.da República site - project expectations a) before and b) after; street imagery c) before (Jun 2014) and d) after (Aug 2018); pedestrian perspective at present e) morning off-peak (10 h–10h30 a.m.) and f) afternoon peak (18 h–18h30 p.m.).

da República and Avenida Fontes Pereira de Melo), linked by a plaza (Saldanha Square), comprehending the redesign of the allocated space for private cars, for public transportation, for parking, for bicycles, and for pedestrians. A new cycling infrastructure was built along the Eixo Central. There were no changes in the local public transportation services (bus, metro, and train) serving the Eixo Central and the control areas.

The Eixo Central intervention area is a consolidated mixed-use area dating from early 20th century when it was designed according to the French "boulevard" urban standards of the time, consisting in a regular grid, with wide and long avenues with tree alignments. It became an important office location and a cluster of private clinics, serving also as one main transportation corridor. There was fierce opposition to the project, namely from car users (especially residents) concerned with having less parking spaces and more congestion due to the reduction of traffic lanes. The implementation started in June 2016 and was finished in February 2017. The project considered distinct design approaches along the Eixo Central, namely within three sections:

1) Avenida da República: A 1.500 m long and 50 m wide avenue with dense (8 stories) occupation, served by bus, underground lines and train.
2) Avenida Fontes Pereira de Melo: A 900 m long and 30 m wide avenue, with a relatively less dense occupation, served by bus and underground lines
3) Saldanha square: A round plaza (65 m radius) connecting the afore-mentioned avenues to other street links.

Figs. 2–4 show the before and after phases of the street interventions using imagery from the Project communication (a, b); from online map services (c, d) and from the pedestrian perspective (September 2019). The interested reader can browse time lapse imagery of the Eixo Central sections from 2009 to 2014 (before) to as recently as 2018 (after) using Google Maps™ Street View application (geolocation details are provided in Appendix B).

Fig. 3. Saldanha site project expectations a) before and b) after; street imagery c) before (Jul 2014) and d) after (Sep 2018); pedestrian perspective at present e) morning off-peak (10 h–10h30 a.m.) and f) afternoon peak (18 h–18h30 p.m.).

Fig. 4. Av. Fontes Pereira de Melo site - project expectations a) before and b) after; street imagery c) before (Jun 2009) and d) after (Sep 2018); pedestrian perspective at present e) morning off-peak (10 h–10h30 a.m.) and f) afternoon peak (18 h–18h30 p.m.).

3. Data collection

We analysed the three sections before and after the intervention, collecting walkability data and pedestrian volumes. We controlled for pedestrian volumes in two control groups: one "adjoining group" consisting of neighbouring locations and one "external group" located in a neighbourhood approximately 1 km away from Eixo Central with comparable urban characteristics. During the implementation of the Eixo Central project, no other environmental interventions occurred in the control locations.

3.1. Walkability

Walkability was assessed for all street segments, i.e. block faces, found in the Eixo Central intervention sections, in a total of 37 street segments (Fig. 1). Of these 20 were located in Av.República; 5 located in Saldanha square and 12 located in Av.Fontes Pereira de Melo. Walkability audits were performed at baseline (June 2016) and follow-up (June 2017) using the IAAPE walkability framework. Previous work tested the tool to uncertainty relating to data collection, finding reliable inter-rater agreement and acceptable robustness (Abreu, 2017). Nonetheless, for convenience, the audits were conducted by the same trained auditor at baseline and follow-up. For each site, data of the individual segments walkability score were aggregated into a mean walkability score using their mean value, in a 0–100 scale. The surrounding area (adjacent and parallel streets) was surveyed for noticeable environment and land use changes. No evident changes in the pedestrian environment were observed therefore walkability scores were assumed constant between the baseline and follow-up period.

3.2. Pedestrian counts

Counting locations were selected considering a combination of factors, namely the variability of the street environment; before-after expectations; existence of previous observations; pilot pedestrian counts; proximity to transit; available resources and operationalization of the counting procedure. The individual street environment presented slight variability, as most physical elements could be found in repetition across and along each street. Yet, we ensured the counting locations to cover both sides of the Eixo Central streets, and to be as spatially distributed as possible. We first selected the locations that reflected the before-after expectations of the project (as depicted in Figs. 2–4), the locations for which we had previous count data, the ones closer and the ones farther to main transit (train, underground). We then performed a series of pilot pedestrian counts in the Eixo Central area and in the control locations, screening out highly correlated locations. We fine-tuned the locations according to the number of available auditors and the operationalization of the counting procedure. One auditor ought to observe pedestrian flows for 10 min within a 90 min period. Given the time lost to preparation and moving between counting locations, we assigned 4 distributed locations per auditor.

In total we were able to monitor 20 locations, of which 11 were distributed in the Eixo Central sites (5 in Av.República; 2 in Saldanha Square; 4 in Av.Fontes Pereira de Melo), 5 in the "adjacent" control area and 4 in the "external" control area, as illustrated in Fig. 1.

Pedestrian flow data was collected *in situ* by a team of trained auditors. Pedestrians were counted using the "gate method" consisting of a tally count of people passing through an imaginary screen line across the sidewalk (Vaughan and Grajewski, 2001). Each counting location was observed for 5 consecutive working days, at 5 counting periods: 1) Morning peak period – 8:00 to 9:30 a.m.; 2) Morning off-peak – 10:00 to 11:30 a.m.; 3) Lunch peak period – 12:30 to 14:00 p.m.; 4) Afternoon off-peak – 15:00 to 16:30 p.m. and 5) Afternoon peak period – 17:00 to 18:30 p.m. Counts were also performed Saturday for 2 counting periods: morning off-peak (10:00–11:30 a.m.) and lunch peak (12:30 to 14:00 p.m.). Given the area's functional characteristics, comparable to a central business district, only the work day flows were used in the analysis. The duration of the counting was determined by the pedestrian flow characteristics, where a period of 10 min was found to provide stable observations (Cambra et al., 2017). The average values for each daily period for each location were used in the statistical analysis, yielding a total of 100 observations (20 locations; 5 time periods). The pedestrian count at baseline took place in the first week of July, from Monday to Friday, between the 4th and the July 8, 2016. The pedestrian count at follow-up took place one year after, between the 3rd and 7th July. Weather conditions were stable and similar in both occasions, consistent of Mediterranean summer: mostly warm (mean average daily temperature = 20 °C; SD = 1.78 °C), dry and sunny days. The observed pedestrian flows (pedestrians/10 min) were converted to an hourly estimation of pedestrian volumes (pedestrians/hour) using the average flow per counting period (Hillier and Iida, 2005). Hence the 25 observed flows per location (5 days, 5 periods) resulted in 5 estimations of pedestrian volume -hourly average of each counting period during the week-per location. The rounded hourly average volumes were then used in the before-after analysis.

3.3. Walking experience

Walking experience was addressed upon completion of the street intervention. We were interested in capturing a self-assessment of the before-and-after experience of people that used the Eixo Central area. A survey was launched at the end of autumn 2017, allowing an experimental period of 6 months after the official inauguration/opening but before harsher weather conditions that could bias the experience rating.

The survey followed a quasi-longitudinal design. People were asked to provide their opinion on the present experience of walking in the streets of Eixo Central as well as to recall their past experience, relating to baseline walking conditions. The walking experience was rated in a 9 point scale, assuming equidistant rating intervals. The lowest score, 1, represented an unpleasant experience, i.e., a street to avoid. Conversely, a score of 9 represented a very pleasant walk. The survey was formatted as a web form, compatible with smartphone use. We asked several local entities to spread the survey through their mailing lists. These included major company offices, two universities located in the area, local government, residents associations and social network forums dedicated to the discussion of local urban issues. The survey was submitted for appreciation and approved by the Board of Administration of Instituto Superior Técnico. All survey respondents were required to grant permission to the use of their data for academic purposes, being warranted anonymity.

3.4. Statistical analysis

We performed paired t-tests to assess the changes in average values of walkability, pedestrian volumes and walking experience between baseline and follow up. The variables of interest were analysed for their suitability of application of parametric tests, setting a valid threshold for skewness and kurtosis values between −2 and +2, having met the required assumptions. The statistical analyses were executed in IBM SPSS version 22, using a significance level of 5%.

4. Results

4.1. Before-after walkability

The implementation of the project produced different environment changes within the 3 sites of Eixo Central. The intervention can be described according to the "7 C" layout of the walkability model as follows:

Connectivity: The pedestrian network structure presented only marginal changes, relating to the repositioning of pedestrian crossings locations. No changes were observed in the control areas.

Convenience: The land use mix remained stable. There were no evident changes in the activities present either in Eixo Central or in the control areas. The buildings under construction or renovation as well as the vacant commercial spaces observed at baseline were not completed nor at use at follow up.

Comfort: The sidewalk pavement quality was improved in Av.República and Saldanha but not in Av.Fontes Pereira de Melo nor in the control area. The change consisted in the implementation of a "comfort stripe" – a stripe made of concrete providing a more regular, smooth and comfortable pavement when compared to the standard Portuguese cobblestoned pavement used in Lisbon.

Conviviality: Kiosks offering drinks and light meals were placed in the plazas created in Saldanha and Av.Fontes Pereira de Melo, providing outdoor sitting places with extended working hours. In Av. República and in the control areas there were no noticeable changes.

Conspicuousness: The new plaza design in the Saldanha and Av.Fontes Pereira de Melo created distinguishable urbanscape elements and a new sense of place.

Coexistence: Crossing safety was targeted by the Eixo Central project. In all main intersections of the area, the turning radius was reduced in order to slow down turning traffic; and crossing refuges were enlarged.

Commitment: Existing regulations on pedestrian accessibility were enforced along the Eixo Central area, namely by levelling sidewalk curbs; providing a minimum obstacle free walking width of 1,5 m; introducing tactile paving at pedestrian crossings. In some cases, in the adjacent streets, these measures were also applied. In the external control area, there was no change.

The aforementioned changes were captured and measured to some extent by the models' indicators and translated into quantitative walkability scores. Table 1 shows the mean walkability score for each site, obtained by the average of the site's individual street segment score.

Average walkability scores show that initial conditions were very similar in the 3 sites, with a score around 71 points. This is a relatively high score when compared to average values of other streets in Lisbon, considering Cambra et al. (2017) who reported an average walkability score of 64 for a comprehensive sample of streets in the same neighbourhood.

While the increase in walkability scores was primarily related to the improvement of pavement quality and comfort, the distinction between each site can be related to the sojourning opportunities introduced, providing a more convivial environment.

On average, we found the difference in before-after walkability to be higher in Saldanha ($M = 10.21$, $SE = 2.48$), $t(4) = 4.11$, $p < .05$, $r = 0.90$; followed by Av. República ($M = 6.57$, $SE = 1.36$), $t(19) = 4.83$, $p < .001$, $r = 0.74$. The change in overall walkability of Av. Fontes Pereira de Melo was positive but not significant ($M = 3.82$, $SE = 3.01$), $t(11) = 1.27$, $p = .23$, $r = 0.36$.

The surrounding area (adjacent and parallel streets) was surveyed for noticeable environment and land use changes. As there were no evident changes in the pedestrian environment, walkability scores were assumed constant between the baseline and follow-up period.

4.2. Before-after pedestrian volume

The average number of pedestrians walking in the Eixo Central increased between baseline and follow up (Table 2). A significant increase was observed in Saldanha ($M = 178$, $SE = 45$) $t(9) = 3.98$, $p < .01$, $r = 0.80$; and in Av. República ($M = 58$, $SE = 16$), $t(24) = 3.56$, $p < .01$, $r = 0.59$; and a positive but less significant change was observed in Av. Fontes Pereira de Melo ($M = 37$, $SE = 18$), $t(19) = 2.03$, $p = .056$, $r = 0.42$.

In the control locations the variation in the average pedestrian volume was not significant. In the adjacent streets there was a slight decrease ($M = -14$, $SE = 14$), $t(24) = -0.98$, $p = .335$, $r = 0.20$; whereas in the external area there was a slight increase ($M = 19$, $SE = 16$), $t(19) = 1.21$, $p = .242$, $r = 0.27$. We found evidence of an increase in the pedestrian volumes of the intervention area following the street renovation. The increase was significant in the Av. República (11.4%; $p < .001$) and Saldanha (29.9%; $p < .001$) sections and marginally significant in Av. Fontes Pereira de Melo section (8.5%; $p = .056$). There was no significant change of the pedestrian volumes in the control streets, either located in the vicinity of the Eixo Central (−3.2%; $p = .335$) or located in a different neighbourhood (3.1%; $p = .242$). We calculated Spearman's rank correlation coefficient s for all pairs of measures. Walkability scores and walking experience were found to be the most correlated (rho = .943; $p < .01$) whilst the other associations showed no statistical significance.

Fig. 5 shows the values for before-after pedestrian volumes in relation to before-after walkability scores. Before the intervention, the walkability scores were relatively similar with an apparent low correlation to pedestrian volumes. The highest pedestrian volumes

Table 1
Comparison of before-after walkability scores.

Intervention site	Walkability Score [0; 100]									
	T1 - Before		T2 -After		Paired samples test					
	Mean	SD	Mean	SD	Mean T2 – T1	SE	t	df	r	p
Av.República	71.86	7.95	78.43	6.23	6.57	1.36	4.83	19	0.74	**.000**
Saldanha	71.03	7.05	81.24	6.21	10.21	2.48	4.11	4	0.90	**.015**
Av.Fontes Pereira de Melo	71.22	9.99	75.04	6.85	3.82	3.01	1.27	11	0.36	.232

Table 2
Comparison of before-after pedestrian flow volumes.

Intervention site	Pedestrian Volume *(pedestrians/hour)*									
	T1 -Before		T2 -After		Paired samples test					
	Mean	SD	Mean	SD	Mean T2-T1	SE	t	df	r	p
Av.República	528	202	586	240	58	16	3.56	24	0.59	**.002**
Saldanha	581	253	758	216	178	45	3.98	9	0.80	**.003**
Av.Fontes Pereira de Melo	424	165	461	152	37	18	2.03	19	0.42	.056
Controls										
Adjacent streets	377	174	363	161	−14	14	−0.98	24	0.20	.335
External area	583	241	602	218	19	16	1.21	19	0.27	.242

were found in Saldanha (M = 581, SD = 254), despite having the lowest average walkability score (M = 71.03, SD = 7.05). After the intervention the values of walkability scores and pedestrian volumes suggest an ordered arrangement.

4.3. Before-after walking experience

We obtained 1.166 completed surveys, of which we screened out people who were not familiar with the intervention area; did not recall the street environment prior to the intervention; or did not visit the area after the intervention. The final valid sample comprised 802 individuals who lived, worked or visited the area. The survey sample characteristics are presented in Table 3.

The survey sample was mainly composed of adult respondents with higher education, mostly workers and visitors. The sample is representative of the users of this city area, being a prime office location, hosting two tertiary education campuses and also being a high-end residential location. However, the senior population was underrepresented in the survey, probably due to the fact that we resorted to a web-based survey.

The self-reported walking experience was similar for the 3 sites at baseline (Table 4). In the 9-levels Likert scale used for assessing walking experience, scores for the initial conditions were slightly above the mean scale value. People reported an increase in their walking experience following the intervention in the 3 studied locations. The difference in walking experience was significantly higher in Saldanha (M = 2.37; $p < .001$), followed by Av. República (M = 2.15; $p < .001$) and Av. FPM (M = 1.92; $p < .001$).

Fig. 6 presents the values for before-after walking experience in relation to before-after walkability scores. Walking experience was found to be very similar in the three sections prior to the intervention, being clustered with the walkability scores. The appreciation of the walking experience after the renovations increased in line with the increase in average walkability score, suggesting also an ordered arrangement. On the other hand the arrangement of the pedestrian volume and walking experience values was maintained, suggesting a somewhat inelastic relation (Fig. 7).

Table 3
Characteristics of the survey sample.

Variable	n	%
Sex		
Female	384	48
Male	418	52
Age group		
<20	21	3
20-34	331	41
35-65	404	50
>65	46	6
Education		
missing	3	0.4
Less than high school	3	0.4
High School	90	11
Technical school	39	5
University or higher	667	84
Activity in the area		
Resident	144	18
Worker/Student	362	45
Visitor	296	37
Employment status		
Worker	513	64
Student	221	28
Retired	44	6
Family caretaker	2	0.2
Unemployed	8	1
Other	14	2

Table 4
Comparison of before-after rating of walking experience.

Intervention site	Walking Experience [1; 9]									
	T1 - Before		T2 - After		Paired samples test					
	Mean	SD	Mean	SD	Mean T2-T1	SE	t	df	r	p
Av.República	4.84	1.57	6.99	1.57	2.16	0.07	29.85	801	0.73	**.000**
Saldanha	4.83	1.67	7.21	1.58	2.37	0.08	28.39	800	0.71	**.000**
Av.Fontes Pereira de Melo	4.63	1.7	6.56	1.7	1.92	0.08	24.87	800	0.66	**.000**

The relation between the three studied variables before and after the intervention are summarized in Figs. 8, 9 and 10 (Appendix A). In order to harmonize the different measurement units the variables were rescaled to a 1–10 measurement scale.

5. Discussion

Our study evaluated the relations of walkability, pedestrian volume and walking experience before and after a street improvement intervention in three connected but distinct sections. We used a longitudinal study design to examine walkability and pedestrian volume, and a quasi-longitudinal design to evaluate the walking experience. The walkability score increased at different levels within each section. The pedestrian volume increased in the intervention sites, while in the control areas no significant change was observed. In addition, people reported a more satisfying walking experience following the intervention. Finally, we found a positive relationship between the magnitude of change in walkability and the changes in pedestrian volume and walking experience.

Our results suggest that walkability, walking experience, and pedestrian flows are related and that the observed change in the pedestrian volumes and walking experience are associated with the change in walkability. This relation highlights the fact that a higher improvement in walkability can be associated with a higher improvement in walking experience as well as to higher pedestrian activity. This was particularly noticeable in the Saldanha section where the change in the pedestrian environment was more intense (Fig. 8). Likewise, a more contentious environmental change was associated with less significant changes in walking experience and pedestrian volumes. This was the case of the Av. Fontes Pereira de Melo section (Fig. 9), where the difference in walkability scores before and after the intervention was not significant.

According to these data, we can infer that using a unidimensional before-after scale to interpret the behaviour effects would have provided mixed or contradictory findings. The mixed findings would be related to having observed an increase in pedestrian volume following a BE intervention in one section whilst observing no increase of pedestrian volume in another area with the same intervention. By using a walkability score to measure the extent and importance of the BE intervention we were able to differentiate between levels of walkability change obtaining a more consistent interpretation of the results. Figs. 8, 9 and 10 illustrate these findings, showing how the observed changes in pedestrian volume and walking experience relate to the measured changes in walkability at each intervention section.

Another relevant finding is that the average pedestrian volume increased only in the intervention area while remaining stable in the adjacent streets and in the external control area. Other studies have reported an increase in pedestrian volumes in retrofitted streets (e.g. Shu et al., 2014; Jensen et al., 2017) but not all studies have included a control area in their observations (Stappers et al., 2018). In comparison, Jung et al. (2017) addressed a comprehensive street intervention program finding that the pedestrian volumes increased not only in the intervention areas but also in control areas, and approximately at the same rate.

In contrast to earlier findings, we were able to observe located and confined effects, thus supporting the hypothesis that a causal link of some extent may exist between walkability improvement and pedestrian activity. However, the present results meet only partially the conditions to establish causality, namely association; time precedence; plausibility and non-spuriousness (Van de Coevering et al., 2015). While time precedence and plausibility conditions can be claimed here, the statistical association and non-spuriousness conditions are less clear. There may be spurious relations to unobserved variables. In particular, tourism has been growing in the city of Lisbon, and the flow of tourists and visitors is noticeable in several parts of the city. Although the studied area is not part of the touristic routes it is possible that some of the increase in the number of people walking is due to tourism.

The present study did not find evidence to support a causal relationship between the increase in walkability and the increase in pedestrian activity. However, the evidence that the increase in pedestrian activity occurred only in the locations where there was a significant change in walkability cannot rule out the hypothesis of a causal relation.

Another interesting finding is that the walking experience increased in all sections, regardless of less significant changes in walkability and pedestrian flow. There are several possible explanations for this result. The first, consistent with Jung et al. (2017), is that smaller scale environmental interventions may be effective in improving the satisfaction of pedestrians whilst being less effective in triggering behaviour change. The second is that improving satisfaction with the walking environment is not a determinant per se to affect pedestrian flow numbers. In accordance, previous studies have demonstrated an increase in pedestrian volume following a decrease in walking experience (Jung et al., 2017). It is possible that the purpose of the walking trip plays a pivotal role in the relation between experience and activity. On one hand, utilitarian walking trips, occurring as a result of necessity could be less responsive to environmental quality (Lindelöw et al., 2014). On the other hand, recreational walking trips, essentially voluntary, could be more sensitive to a satisfactory pedestrian environment (Kim et al., 2014).

Concomitantly, providing a more pleasurable experience may be a prerequisite in shaping a specific walking behaviour, in particular in recreational or non-transportation bouts. The prominent physical factors influencing walking experience seem to be related to the aesthetic quality of the built environment (Dadpour et al., 2016), its imageability (Ameli et al., 2015), the available space to walk, and presence of green elements, such as trees (Kim et al., 2014). The Eixo Central project enhanced the public space thus affecting the aesthetic and imagistic qualities of the environment, as well as increasing the pedestrian space. It is interesting to note that while the aesthetic factors believed to influence walking experience are not addressed by the 7 C layout of the walkability assessment model, still a positive and significant correlation was found between the walkability score and the reported experience. Hence, some of the 7 C layout factors seem to be also relevant in influencing walking experience.

5.1. Strengths and limitations

Environmental interventions occur at different scales, ranging from isolated aesthetics enhancements to the provision of new infrastructure. Examining possible behavioural outcomes of such interventions without considering the context and scale of the intervention may blur the interpretation of results. The present study has provided a systematic before-after evaluation of a street improvement intervention, assessing changes in walkability, pedestrian volumes and walking experience. Key strengths of this study include the use of a validated walkability assessment model to assess the extent of the environmental change and the application of a quasi-experimental study design to examine pedestrian volumes using two control areas to better isolate the potential effects in walking levels.

There are however limitations that should be considered when interpreting the results, namely relating to the assessment of walkability and walking experience. There were noticeable environmental changes that were not fully captured by the walkability model, relating to design qualities such as imageability, enclosure and human scale (Ewing and Handy, 2009; Ameli et al., 2015) and to the provision of amenities and greenery. For instance, in Av. República, the sidewalks were enlarged by more than 2 m (taking up a parking lane) doubling their width, consequently changing the centreline perspective of the street. In Saldanha, the plaza layout provided more open public space for walking and sojourning. In Av. Fontes Pereira de Melo, there was also a plaza created but the majority of the street kept the original design. The enlargement of the sidewalks changed the perspective of the pedestrian in relation to the street, providing a different reading of the human scale in comparison to the motorized traffic space. Also, replacing traffic lanes by pedestrian space led to fewer nuisances from close traffic.

New amenities were installed in all Eixo Central sites, namely benches, LED lighting oriented to the sidewalk, greenery, and trees. Some of these factors are often considered relevant in other walkability assessment models. The IAAPE walkability assessment framework was developed using a participatory method for selecting and ranking relevant factors, involving local stakeholders (Moura et al., 2017). None of the panels who participated in the selection and ranking of walkability factors regarded indicators as greenery or lighting as being meaningful in their perception of a walking friendly environment, contrasting to other studies. A study by Dauden et al. (2009) found that greenery was one of the most important factors for pedestrians in Spanish cites, whose built and social environments share some similarities to the ones found in Lisbon. Perhaps in the local context of Lisbon other factors are perceived as more relevant by people at present. In accordance to Alfonzo's model of hierarchy of walking needs (Alfonzo, 2005) it could be expected that upon satisfaction of basic concerns (e.g. pavement quality) other concerns gain more relevance (e.g. greenery).

Also, it may be that what people consider to be pedestrian friendly is somewhat different of what people consider to be a pleasurable walking experience. The former concept may be more related to the physical interaction with the environment while the latter may be more related to the sensorial and emotional interaction. Refining the methods for assessing walking experience will be a necessary step to further investigate the role of environmental change in providing a more pleasurable experience which in turn may favour walking. Recent research has addressed the development of travel satisfaction scales (Ettema et al., 2011; De Vos et al., 2015), also with a focus in measuring walking experience (Johansson et al., 2017; De Vos, 2018). For instance, Johansson et al. (2017) used on-site, walking along, questionnaires based on a 15 item Likert scale to address walking experience, finding that the affective experience of walking mediated the effect of perceived urban design qualities in the intention to walk. Multiple measurement scales may provide stronger report measures than single-item questions used in the present study and similar ones (Jung et al., 2017). Future studies should consider controlling for factors such as seasonal variation and attachment to the study area amongst others.

As argued by Jacobs (1993) it is possible that the social environment plays a bigger role in attracting people to a street than the physical environment, and therefore the results of this study may not be generalized to other urban contexts. Other prospective studies are encouraged to assemble a catalogue of before-after assessment studies in different urban contexts and geographies and to consolidate walkability measures that can provide a solid basis for benchmarking. Further research could usefully explore the use of different walkability measurement approaches in order to strengthen the evidence on the relation between walkability improvement and behaviour change.

Eventually, comprehensive longitudinal evaluations of environmental changes will require improved walkability scoring tools that are sensitive to change in micro-scale factors and to urban design qualities. The development of these tools and the availability of open data (e.g. automated pedestrian counts) should also contribute to overcome the inherent challenges of documenting the effects of pedestrian interventions. But it is important to note, in accordance to Krizek et al. (2009) that the body of intervention studies will only grow if policy makers, communities and researchers work together for rigorous and timely evaluations.

5.2. Conclusions

This study evaluated the relations of walkability, pedestrian volumes and walking experience before and after a comprehensive street intervention. To the best of our knowledge no previous studies have provided a systematic evaluation of these three factors combined. The evidence found suggests that the scale of environmental interventions matters for triggering effects in walking behaviour. Smaller scale interventions, affecting single micro-factors may not be as effective in influencing walking behaviour as larger scale interventions where a change in walkability *de facto* takes place. In other words, making people walk more may require substantial environmental change. On the other hand smaller scale interventions seem to be effective in increasing the pedestrian satisfaction. Policy-wise, targeting the improvement of the population satisfaction can be a goal on its own hence smaller scale street improvements could be also considered to be successful. In this regard, the understanding of what constitutes a successful intervention to promote walking requires further reflection.

Further research is needed also to better understand the role of experience as a mediator between the perceived environment and active travel behaviour and to discern which population groups may be more reactive to changes in the built environment. The understanding of which factors are more influential to whom and which synergies between the factors can provide more accomplished results are key to guide future urban interventions and policies aimed at increasing walking.

Financial disclosure

The authors acknowledge the support for this research by the Portuguese Foundation for Science and Technology (FCT), through the Ph.D. grant PD/BD/105719/2014.

CRediT authorship contribution statement

Paulo Cambra: Conceptualization, Methodology, Validation, Investigation, Resources, Writing - original draft, Writing - review & editing, Visualization. **Filipe Moura:** Supervision, Project administration, Funding acquisition, Conceptualization, Methodology, Validation, Writing - review & editing.

Acknowledgments

The authors acknowledge the support for this research by the Portuguese Foundation for Science and Technology (FCT), through the Ph.D. grant PD/BD/113735/2015.

The authors also acknowledge the Mobility Observatory of the Portuguese Automobile Club for supporting the pedestrian counts in 2016 and the Municipality of Lisbon for supporting the pedestrian counts in 2017.

The authors are grateful to the peer reviewers for their insightful comments on earlier versions of the manuscript.

Appendix B. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jth.2019.100797.

Appendix A

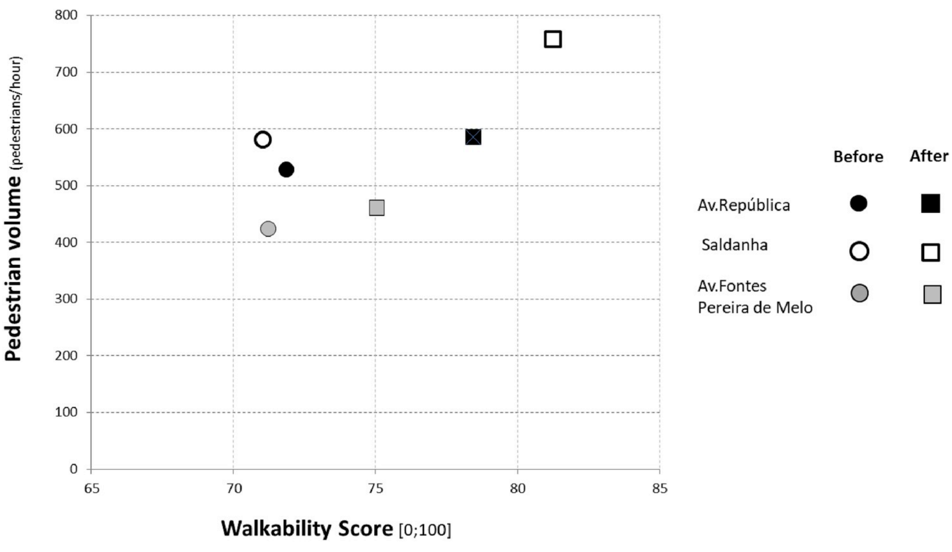

Fig. 5. Graphical evaluation of the Before-After changes in the pedestrian volume in relation to measured walkability at each intervention site.

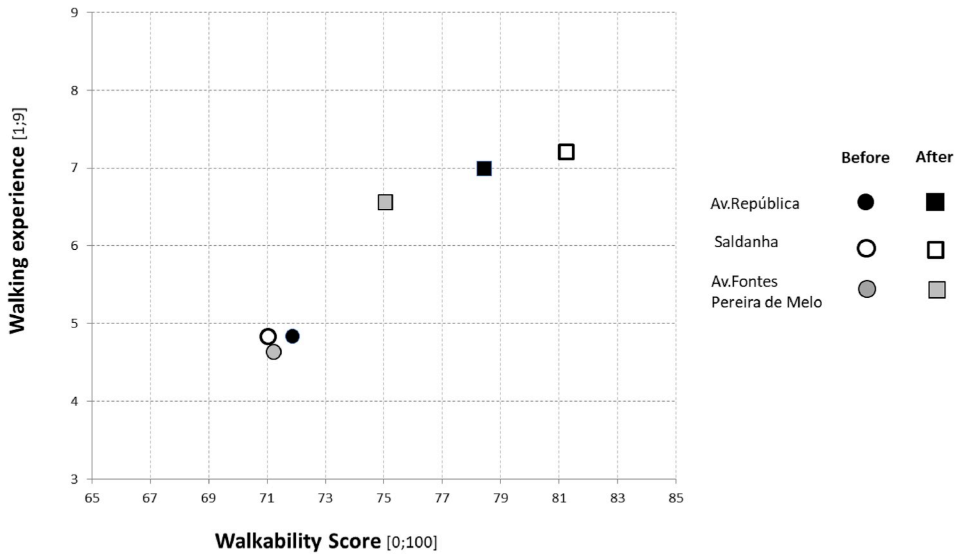

Fig. 6. Graphical evaluation of the Before-After changes in surveyed walking experience in relation to measured walkability at each intervention site.

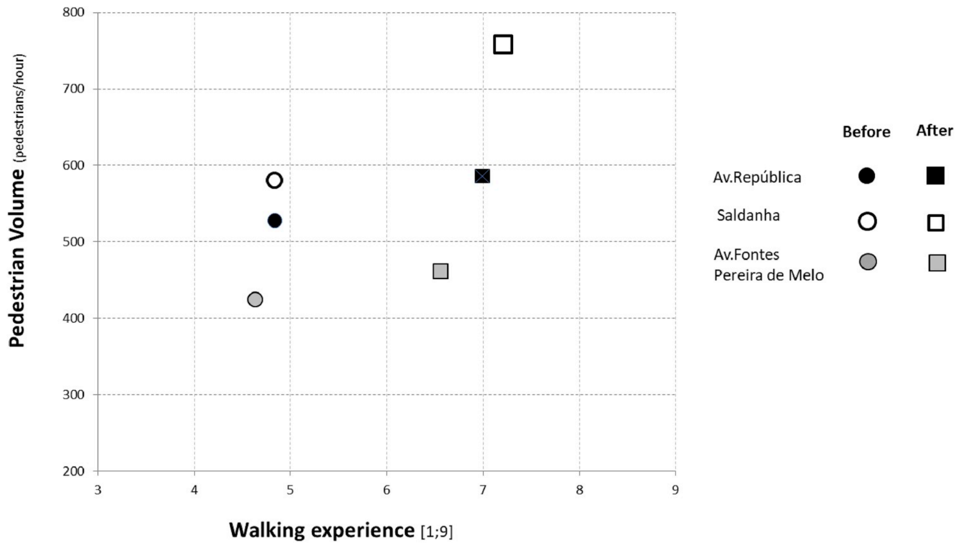

Fig. 7. Graphical evaluation of the Before-After changes in the pedestrian volume in relation to surveyed walking experience at each intervention site

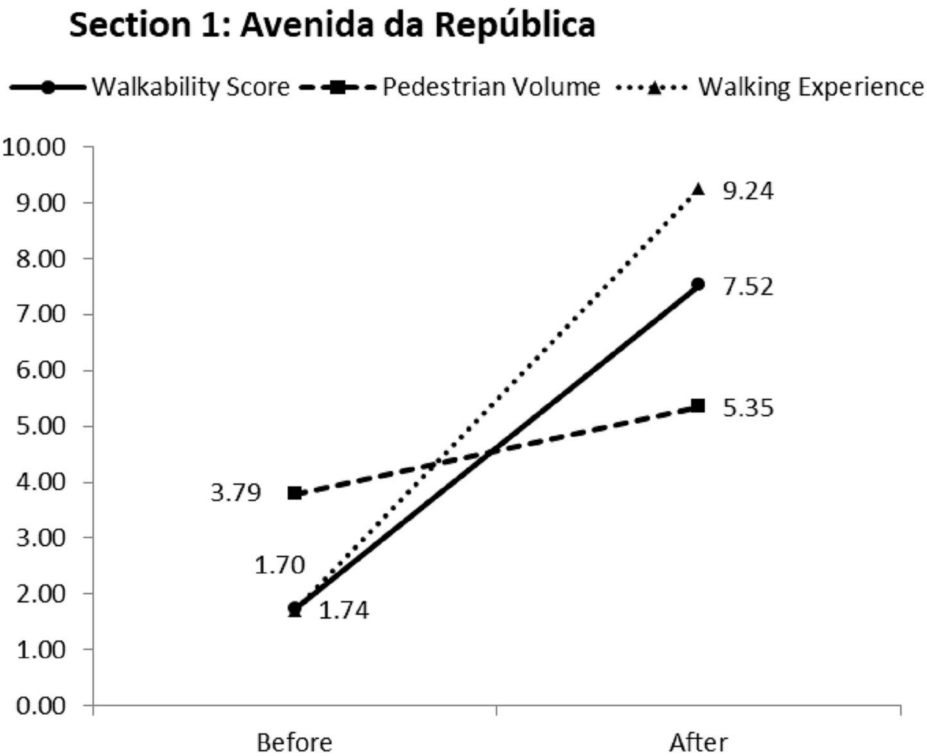

Fig. 8. Walkability score, pedestrian volume and walking experience before and after intervention at section 1) Avenida da República.[1]

[1] RescaledValue=((10-1)/(Max(Observed)-Min(Observed))*((Value(Observed)-Max(Observed))+10.

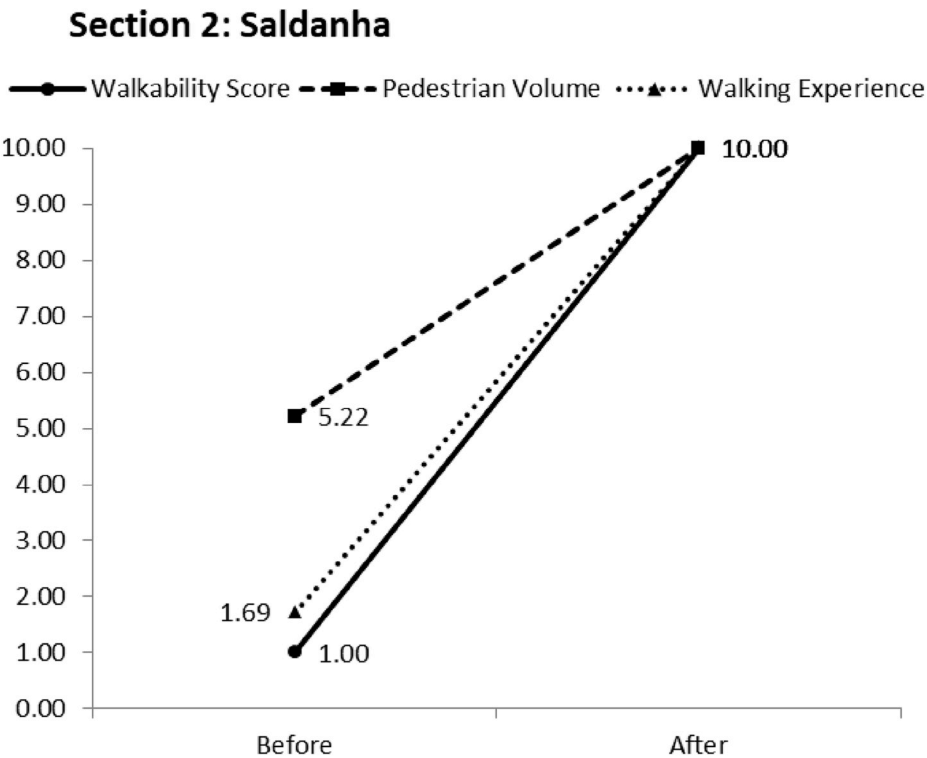

Fig. 9. Walkability score, pedestrian volume and walking experience before and after intervention at section 2) Saldanha[1]

[1] RescaledValue=((10-1)/(Max(Observed)-Min(Observed))*((Value(Observed)-Max(Observed))+10.

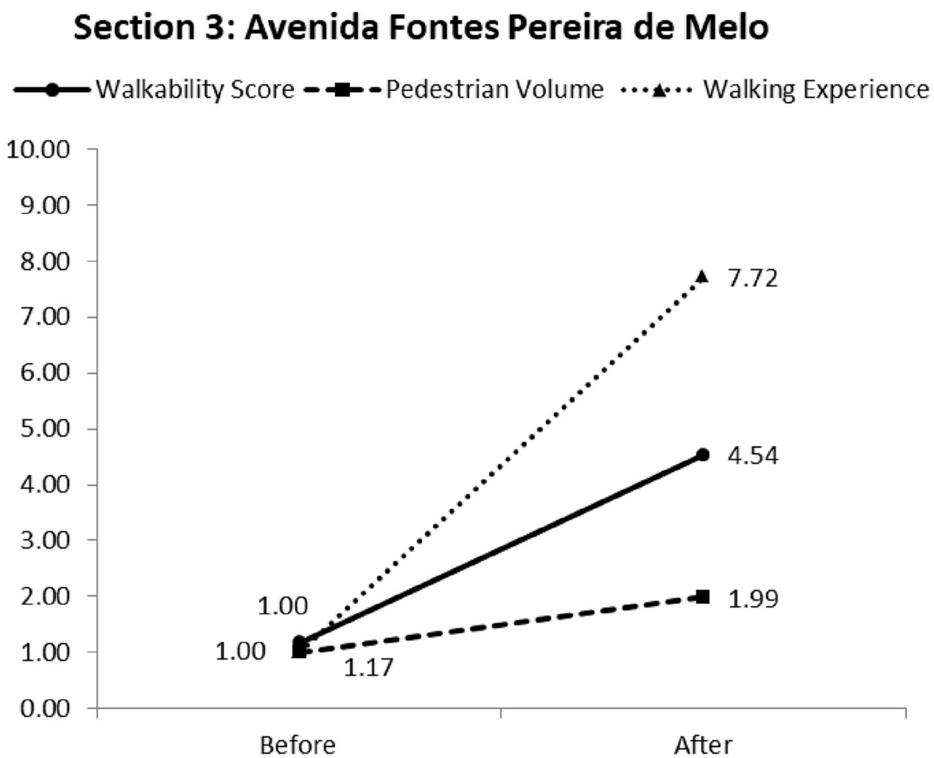

Fig. 10. Walkability score, pedestrian volume and walking experience before and after intervention at section 3) Avenida Fontes Pereira de Melo[1]
[1] RescaledValue=((10-1)/(Max(Observed)-Min(Observed))*((Value(Observed)-Max(Observed))+10.

References

Abreu, D., 2017. Teste à robustez do método de avaliação de caminhabilidade IAAPE (Testing the robustness of the IAAPE walkability assessment method). Instituto Superior Técnico, University of Lisbon. Available at: https://fenix.tecnico.ulisboa.pt/downloadFile/1126295043835618/Dissertacao_final2.0_CORRECCOES.pdf.

Adkins, A., Dill, J., Luhr, G., Neal, M., 2012. Unpacking walkability: testing the influence of urban design features on perceptions of walking environment attractiveness. J. Urban Des. 17, 499–510. https://doi.org/10.1080/13574809.2012.706365.

Alfonzo, M.A., 2005. To walk or not to walk? The hierarchy of walking needs. Environ. Behav. 37, 808–836. https://doi.org/10.1177/0013916504274016.

Ameli, S.H., Hamidi, S., Garfinkel-Castro, A., Ewing, R., 2015. Do better urban design qualities lead to more walking in Salt Lake city, Utah? J. Urban Des. https://doi.org/10.1080/13574809.2015.1041894.

Asadi-Shekari, Z., Moeinaddini, M., Zaly Shah, M., 2013. Non-motorised level of service: addressing challenges in pedestrian and bicycle level of service. Transp. Rev. 33, 166–194. https://doi.org/10.1080/01441647.2013.775613.

Behrens, R., Mistro, R. Del, 2010. Shocking Habits : methodological issues in analyzing changing personal travel behavior over time shocking Habits : methodological issues in. Int. J. Sustain. Transp. 4, 253–271. https://doi.org/10.1080/15568310903145170.

Bornioli, A., Parkhurst, G., Morgan, P.L., 2018. Psychological wellbeing benefits of simulated exposure to five urban settings: an experimental study from the Pedestrian's perspective. J. Transp. Health 9, 105–116. https://doi.org/10.1016/j.jth.2018.02.003.

Cain, K.L., Gavand, K.A., Conway, T.L., Geremia, C.M., Millstein, R.A., Frank, L.D., Saelens, B.E., Adams, M.A., Glanz, K., King, A.C., Sallis, J.F., 2017. Developing and validating an abbreviated version of the Microscale Audit for Pedestrian Streetscapes (MAPS-Abbreviated). J. Transp. Health 5, 84–96. https://doi.org/10.1016/j.jth.2017.05.004.

Cain, K.L., Geremia, C.M., Conway, T.L., Frank, L.D., Chapman, J.E., Fox, E.H., Timperio, A., Veitch, J., Dyck, D. Van, Verhoeven, H., Reis, R., Augusto, A., Cerin, E., Mellecker, R.R., Queralt, A., Molina-garcía, J., Sallis, J.F., 2018. Development and reliability of a streetscape observation instrument for international use : MAPS-global. Int. J. Behav. Nutr. Phys. Act. 15, 1–11. https://doi.org/10.1186/s12966-018-0650-z.

Cambra, P., Moura, F., Gonçalves, A., 2017. On the correlation of pedestrian flows to urban environment measures: a Space Syntax and Walkability Analysis comparison case. In: Proceedings of the 11th Space Syntax Symposium, pp. 1–21. Lisbon.

Cambra, P., Gonçalves, A.B., Moura, F., 2019. The digital pedestrian network in complex urban contexts : a primer discussion on typological specifications. Finisterra LIV 155–170. https://doi.org/10.18055/Finis16414.

Cao, X., Mokhtarian, P.L., Handy, S.L., 2007. Do changes in neighborhood characteristics lead to changes in travel behavior? A structural equations modeling approach. Transportation (Amst). 34, 535–556. https://doi.org/10.1007/s11116-007-9132-x.

Cervero, R., Kockelman, K., 1997. Travel demand and the 3Ds: density, diversity, and design. Transp. Res. D Transp. Environ. 2, 199–219. https://doi.org/10.1016/S1361-9209(97)00009-6.

Chapman, R., Howden-chapman, P., Keall, M., Witten, K., Abrahamse, W., Woodward, A., Muggeridge, D., Beetham, J., Grams, M., 2014. Increasing active travel : aims , methods and baseline measures of a quasi-experimental study. BMC Public Health 14, 1–12.

Dadpour, S., Pakzad, J., Khankeh, H., 2016. Understanding the influence of environment on adults' walking experiences: a meta-synthesis study. Int. J. Environ. Res. Public Health. https://doi.org/10.3390/ijerph13070731.

Dauden, F., Echavarri, J., Schettino, M., 2009. La ciudad paseable. Ministerio de Fomento - España. Ministry of Public Works and Transport of Spain, Madrid.

De Vos, J., 2018. Towards happy and healthy travellers: a research agenda. J. Transp. Health 11, 80–85. https://doi.org/10.1016/j.jth.2018.10.009.

De Vos, J., Schwanen, T., Van Acker, V., Witlox, F., 2015. How satisfying is the scale for travel satisfaction? Transp. Res. F Traffic Psychol. Behav. 29, 121–130. https://doi.org/10.1016/j.trf.2015.01.007.

Ettema, D., Gärling, T., Eriksson, L., Friman, M., Olsson, L.E., 2011. Satisfaction with travel and subjective well-being : development and test of a measurement tool. Transp. Res. Part F Psychol. Behav. 14, 167–175. https://doi.org/10.1016/j.trf.2010.11.002.

Ewing, R., Hajrasouliha, A., Neckerman, K.M., Purciel-hill, M., Greene, W., 2016. Streetscape features related to pedestrian activity. J. Plan. Educ. Res. 36, 5–15. https://doi.org/10.1177/0739456X15591585.

Ewing, R., Handy, S., 2009. Measuring the unmeasurable: urban design qualities related to walkability. J. Urban Des. 14, 65–84. https://doi.org/10.1080/13574800802451155.

Ferreira, I.A., Johansson, M., Sternudd, C., Fornara, F., 2016. Transport walking in urban neighbourhoods-Impact of perceived neighbourhood qualities and emotional relationship. Landsc. Urban Plan. 150, 60–69. https://doi.org/10.1016/j.landurbplan.2016.02.009.

Foltête, J.C., Piombini, A., 2007. Urban layout, landscape features and pedestrian usage. Landsc. Urban Plan. 81, 225–234. https://doi.org/10.1016/j.landurbplan.2006.12.001.

Forsyth, A., Krizek, K.J., 2010. Promoting walking and bicycling: assessing the evidence to assist planners. Built. Environ. 36, 429–446. https://doi.org/10.2148/benv.36.4.429.

Frank, L.D., Schmid, T.L., Sallis, J.F., Chapman, J., Saelens, B.E., 2005. Linking objectively measured physical activity with objectively measured urban form: findings from SMARTRAQ. Am. J. Prev. Med. 28, 117–125. https://doi.org/10.1016/j.amepre.2004.11.001.

Frank, L.D., Sallis, J.F., Conway, T.L., Chapman, J.E., Saelens, B.E., Bachman, W., 2006. Many pathways from land use to health. J. Am. Plan. Assoc. 72, 75–87.

Gebel, K., Bauman, A.E., Petticrew, M., 2007. The physical environment and physical activity. A critical appraisal of review articles. Am. J. Prev. Med. 32 https://doi.org/10.1016/j.amepre.2007.01.020.

Gehl, J., 2010. Cities for People, Places. Island Press. https://doi.org/10.1017/CBO9781107415324.004.

Gehl, J., 1987. Life between Buildings, 2011th ed. Island Press, Washington.

Hall, C.M., Ram, Y., 2018. Walk score® and its potential contribution to the study of active transport and walkability: a critical and systematic review. Transp. Res. D Transp. Environ. 0–1. https://doi.org/10.1016/j.trd.2017.12.018.

Handy, S., Cao, X., Mokhtarian, P., 2005. Correlation or causality between the built environment and travel behavior? Evidence from Northern California. Transp. Res. D Transp. Environ. 10, 427–444. https://doi.org/10.1016/j.trd.2005.05.002.

Hillier, B., Iida, S., 2005. Network and psychological effects: a theory of urban movement. In: Spatial Information Theory. Springer, pp. 475–490.

Holle, V. Van, Deforche, B., Cauwenberg, J. Van, Goubert, L., Maes, L., Weghe, N. Van De, Bourdeaudhuij, I. De, 2012. Relationship between the physical environment and different domains of physical activity in European adults : a systematic review. BMC Public Health 12, 1. https://doi.org/10.1186/1471-2458-12-807.

Isaacs, R., 2010. The urban Picturesque : an aesthetic experience of urban pedestrian places. J. Urban Des. 4809, 145–180. https://doi.org/10.1080/713683961.

Jacobs, A.B., 1993. Great Streets. MIT Press, Cambridge, Mass.

Jensen, W.A., Stump, T.K., Brown, B.B., Werner, C.M., Smith, K.R., 2017. Walkability , complete streets , and gender : who bene fi ts most ? Health Place 48, 80–89. https://doi.org/10.1016/j.healthplace.2017.09.007.

Johansson, M., Sternudd, C., Kärrholm, M., 2017. Perceived urban design qualities and affective experiences of walking. J. Urban Des. 21, 257–276. https://doi.org/10.1080/13574809.2015.1133225.

Jung, H., Lee, S., Sung, H., Seung, J., 2017. Does improving the physical street environment create satisfactory and active streets ? Evidence from Seoul ' s Design Street Project. Transp. Res. Part D 50, 269–279. https://doi.org/10.1016/j.trd.2016.11.013.

Krizek, K.J., Handy, S.L., Forsyth, A., 2009. Explaining changes in walking and bicycling behavior: challenges for transportation research. Environ. Plan. Plan. Des. 36, 725–740. https://doi.org/10.1068/b34023.

Keall, M., Chapman, R., Howden-Chapman, P., Witten, K., Abrahamse, W., Woodward, A., 2015. Increasing active travel: results of a quasiexperimental study of an intervention to encourage walking and cycling. J. Epidemiol. Community Health 69, 1184–1190. https://doi.org/10.1136/jech-2015-205466.

Kim, S., Park, S., Lee, J.S., 2014. Meso- or micro-scale? Environmental factors influencing pedestrian satisfaction. Transp. Res. D Transp. Environ. 30, 10–20. https://doi.org/10.1016/j.trd.2014.05.005.

Lee, C., Moudon, A.V., 2004. Physical activity and environment research in the health field: implications for urban and transportation planning practice and research. J. Plan. Lit. 19, 147–152. https://doi.org/10.1177/0885412204267680.

Lee, S., Talen, E., 2014. Measuring walkability: a note on auditing methods. J. Urban Des. 19, 368–388. https://doi.org/10.1080/13574809.2014.890040.

Leslie, E., Coffee, N., Frank, L., Owen, N., Bauman, A., Hugo, G., 2007. Walkability of local communities: using geographic information systems to objectively assess relevant environmental attributes. Health Place 13, 111–122. https://doi.org/10.1016/j.healthplace.2005.11.001.

Lindelöw, D., Svensson, Å., Sternudd, C., Johansson, M., 2014. What limits the pedestrian ? Exploring perceptions of walking in the built environment and in the context of every-day life. J. Transp. Health 1, 223–231. https://doi.org/10.1016/j.jth.2014.09.002.

Lynch, K., 1960. The Image of the City. MIT Press, Cambridge, USA.

Milakis, D., van Wee, B., 2018. "For me it is always like half an hour": exploring the acceptable travel time concept in the US and European contexts. Transp. Policy 64, 113–122. https://doi.org/10.1016/j.tranpol.2018.02.001.

Millstein, R.A., Cain, K.L., Sallis, J.F., Conway, T.L., Geremia, C., Frank, L.D., Chapman, J., Dyck, D. Van, Dipzinski, L.R., Kerr, J., Glanz, K., Saelens, B.E., 2013. Development , Scoring , and Reliability of the Microscale Audit of Pedestrian Streetscapes (MAPS).

Moura, F., Cambra, P., Gonçalves, A.B., 2017. Measuring walkability for distinct pedestrian groups with a participatory assessment method: a case study in Lisbon. Landsc. Urban Plan. 157 https://doi.org/10.1016/j.landurbplan.2016.07.002.

Ogilvie, D., Mitchell, R., Mutrie, N., Petticrew, M., Platt, S., 2006. Evaluating health effects of transport interventions. Methodologic case study. Am. J. Prev. Med. 31, 118–126. https://doi.org/10.1016/j.amepre.2006.03.030.

Ogilvie, D., Foster, C.E., Rothnie, H., Cavill, N., Hamilton, V., Fitzsimons, C.F., Mutrie, N., Scottish Physical Activity Research Collaboration, 2007. Interventions to promote walking: systematic review. BMJ 334, 1204. https://doi.org/10.1136/bmj.39198.722720.BE.

Panter, J., Heinen, E., Mackett, R., Ogilvie, D., 2016. Impact of new transport infrastructure on walking, cycling, and physical activity. Am. J. Prev. Med. 50 (2), 45–53. https://doi.org/10.1016/j.amepre.2015.09.021.

Pazin, J., Garcia, L., Florindo, A., Peres, M., Guimarães, A., Borgatto, A., Duarte, M., 2016. Effects of a new walking and cycling route on leisure-time physical activity of Brazilian adults: A longitudinal quasi-experiment. Heal. Place 39, 18–25. https://doi.org/10.1016/j.healthplace.2016.02.005.

Saelens, B.E., Sallis, J.F., 2002. Neighborhood environment walkability scale (NEWS). Am. J. Public Health 93, 78–81. https://doi.org/10.1016/j.ypmed.2009.07.011.

Shadish, W.R., Cook, T.D., Campbell, D.T., 2002. Experimental and Designs for Generalized Causal Inference. Houghton, Mifflin and Company, Boston, MA.

Shu, S., Quiros, D.C., Wang, R., Zhu, Y., 2014. Changes of street use and on-road air quality before and after complete street retrofit: An exploratory case study in Santa Monica, California. Transp. Res. Part D Transp. Environ. 32, 387–396. https://doi.org/10.1016/j.trd.2014.08.024.

Stappers, N.E.H., Kann, D.H.H. Van, Ettema, D., Vries, N.K. De, Kremers, S.P.J., 2018. Health & Place the e ff ect of infrastructural changes in the built environment on physical activity , active transportation and sedentary behaviour – a systematic review. Health Place 53, 135–149. https://doi.org/10.1016/j.healthplace.2018.08.002.

Sun, G., Oreskovic, N.M., Lin, H., 2014. How do changes to the built environment influence walking behaviours? a longitudinal study within a university campus in Hong Kong. Int. J. Health Geogr. 13, 28. https://doi.org/10.1186/1476-072X-13-28.

Vale, D.S., 2013. Does commuting time tolerance impede sustainable urban mobility? Analysing the impacts on commuting behaviour as a result of workplace relocation to a mixed-use centre in Lisbon. J. Transp. Geogr. 32, 38–48. https://doi.org/10.1016/j.jtrangeo.2013.08.003.

Vale, D.S., Saraiva, M., Pereira, M., 2015. Active accessibility: a review of operational measures of walking and cycling accessibility. J. Transp. Land Use 1. https://doi.org/10.5198/jlu.2015.593.

Van de Coevering, P., Maat, K., Van Wee, B., 2015. Multi-period research designs for identifying causal effects of built environment characteristics on travel behaviour. Transp. Rev. 35, 512–532. https://doi.org/10.1080/01441647.2015.1025455.
Vaughan, L., Grajewski, T., 2001. Space Syntax Observation Manual. University College London.
Wang, H., Yang, Y., 2019. Neighbourhood walkability: a review and bibliometric analysis. Cities 93, 43–61. https://doi.org/10.1016/j.cities.2019.04.015.