International Journal of Transportation Science and Technology 7 (2018) 254–263

Contents lists available at ScienceDirect

International Journal of Transportation Science and Technology

journal homepage: www.elsevier.com/locate/ijtst

Investigating the relation of highway design standards with network-level walkability: The case study of Luxembourg

Maurice Nilles[a], Ioannis Kaparias[b,*]

[a] *Schroeder & Associés S.A., Luxembourg City, Luxembourg*
[b] *Transportation Research Group, University of Southampton, UK*

A R T I C L E   I N F O

Article history:
Received 4 January 2018
Received in revised form 10 July 2018
Accepted 13 August 2018
Available online 22 August 2018

Keywords:
Walkability
Pedestrian
Highway design

A B S T R A C T

This study assesses the disparity between good street design practice and highway design standards with respect to walkability. Using an example local network in the commune of Lorentzweiler in Luxembourg, the study first performs a large-scale network-level walkability evaluation using the well-established Pedestrian Environment Review System (PERS) pedestrian audit method in order to identify design shortcomings around the network. Then, focusing on the shortcomings identified, the study evaluates the findings with respect to the existing highway design standards of Luxembourg, highlights gaps in the latter and proposes amendments and additions that would enhance the walkability element in the design of new schemes and the retrofitting of existing ones.

1. Introduction

Traditionally, street design and traffic engineering have been driven by the concept of segregation of pedestrians and vehicles. As such, the priority has been to allow for quicker access and movement of the vehicular traffic by limiting conflicts and human-dependent decisions and by designing streets according to the desire-lines of vehicle drivers. As opposed to that, the desire-paths of pedestrians have often been neglected, with highway design guidance foreseeing features such as pedestrian subways, bridges, guardrails and walls, restricting the movement of pedestrians with the objective of protecting them and preventing their involvement in road accidents.

In recent years, however, there has been a trend away from traffic segregation, driven by developments in architecture and urban planning. Instead, street design and traffic engineering have seen a shift in focus from vehicles to pedestrians as a means of creating a better environment, mainly through the re-allocation of more space to the latter and the removal of features such as street furniture, signage, delineation and kerbs. Notable examples include the Complete Streets initiative in the USA and the shared space concept in the UK.

In light of the increasing importance of catering for pedestrians in urban street design and traffic engineering, the review and assessment of the walkability is becoming an essential constituent of any new scheme or redevelopment, alongside the conventional assessment of the traffic efficiency, before and after implementation. This is generally carried out using well-established comprehensive pedestrian audit tools. But despite the latest developments in design practices being reflected in

Peer review under responsibility of Tongji University and Tongji University Press.
* Corresponding author.
E-mail address: i.kaparias@southampton.ac.uk (I. Kaparias).

https://doi.org/10.1016/j.ijtst.2018.08.001
2046-0430/

such tools, this is often not the case with highway design standards, which are updated more infrequently and appear, in many cases, outdated and inappropriate, still focusing predominantly on vehicle traffic.

The objective of this study is, hence, to assess the disparity between good street design practice and highway design standards with respect to walkability. Using an example local network in the commune of Lorentzweiler in Luxembourg, the study first applies the well-established PERS pedestrian audit methodology in order to identify design shortcomings in terms of walkability around the network. Then, focusing on the shortcomings identified, the study evaluates the findings with respect to existing highway design standards, highlights gaps in the latter and proposes amendments and additions that would enhance the walkability element in the design of new schemes.

The paper is structured as follows. Section 2 reviews the relevant background in terms of previous work on pedestrian environment evaluation and introduces the PERS methodology used in this study. Section 3 then introduces the national context of the study, including a brief description of the Lorentzweiler study area and an outline of the applicable highway design standards. The analysis using the PERS methodology and the comparison with the design standards is described in Section 4. Finally, Section 5 concludes the paper and identifies areas of future work.

2. Background

This section sets out the background of the study by providing a review of the topic of pedestrian environment evaluation, as well as a brief description of the PERS methodology, which forms the foundation of the analysis.

2.1. Pedestrian environment evaluation

A variety of methods have been developed with the aim of assessing the street environment from the pedestrians' point of view in order to be able to address their needs. These methods usually involve the conduct of surveys with pedestrians, covering aspects such as the accessibility of the area, the availability of the required street furniture, the availability of the required services, the aesthetic appearance and the cleanliness of the space. However, since external environments are subject to users who have different tastes and needs, what is important for one user may be less important for another, thus making it a necessity to find a common standard for the comparison.

Previous research has attempted to address the topic of pedestrian environment assessment by identifying the key influencing factors and developing appropriate tools. While attempts have been made to evaluate pedestrian facilities objectively, it has been highlighted in the literature that many of the factors involved are subjective in nature, and as such studies have adopted various approaches (Talen, 2008). Examples include: a method presented by Sarkar (1993), which defines a level of service measure for pedestrian movement based on safety, security, comfort and convenience, continuity, system coherence, and attractiveness; a study by Pikora et al. (2002), evaluating the quality of walking as a function of four criteria (functional, safety, aesthetic and destinations); and the works of Emery et al. (2003) and Day et al. (2006), which assess features such as the condition of pavements and sidewalks, safety, lighting, aesthetics, and public transport facilities. Further methods and tools are presented and comprehensively appraised by Vernez-Moudon and Lee (2003) and by Aghaabbasi et al. (2017).

With regard to the collection of data for the evaluation, there are two prominent approaches that are usually employed. The first approach focuses on general assessment of the pedestrian perceptions of a space and therefore uses questionnaires to survey pedestrians. Surveys may be carried out on-street or offline, may involve standardised methods and tools or ad-hoc purpose-developed questionnaires, and may be targeting different numbers of respondents depending on the desired level of detail and statistical significance level. Examples of standardised tools include:

- the Neighbourhood Environment Walkability Survey (NEWS) tool (Saelens et al., 2003), which asks pedestrians to describe their walking environment and experience as a function of a number of attributes, such as sidewalk presence, maintenance, lighting and cleanliness;
- the Liveable Communities tool (Kihl et al., 2005) and the Twin Cities Walking Survey (Forsyth et al., 2009), which consider predominantly the walking environment from the viewpoint of aged pedestrians; and
- the Neighbourhood Sidewalk Assessment Tool (NSAT) (Aghaabbasi et al., 2017), which focuses on the microscale sidewalk design factors at the neighbourhood level.

On the other hand, an example of an ad-hoc survey is a 2007 assessment of pedestrian perceptions at London's Oxford Circus site, commissioned by Transport for London and carried out by Atkins Intelligent Space (2008), which enquired visitors to the area about their perception of public transport services, way-finding into and around the area, the ease of moving around the space and their perceived safety. The study eventually helped clarify important problems relating to the pedestrian environment, in light of the subsequent redevelopment of the space in 2010, and was also coupled with an after-study using a similar questionnaire, which demonstrated improvements in the aspects identified (Mercieca et al., 2011).

The second approach comprises comprehensive analysis (audit) tools for pedestrian environments offering standardised methods of measuring pedestrian views. Such tools are intended for use by expert surveyors and/or interviewees and involve the collection of detailed information about multiple parameters of the pedestrian environment, many of which may not be noticed by "ordinary" pedestrians. Notable examples include:

- the Path Environment Audit Tool (PEAT) (Troped et al., 2006), which focuses predominantly on the provision and evaluation of features assisting mobility-impaired pedestrians;
- the Walking Suitability Assessment Form (WSAF) (Emery et al., 2003), which concentrates on the "hard" engineering aspects of walkways, such as materials, surface condition and width;
- the PIN3 neighbourhood audit instrument (Evenson et al., 2009) and the Irvine Minnesota inventory (I–M) tool (Boarnet et al., 2006), which, in addition to the "hard" engineering aspects also consider "softer" features, such as trees casting shade along walkways;
- the tool developed by Galanis and Eliou (2011, 2012), which defines a comprehensive list of walkability indicators, classified into infrastructure and street furniture ones, and uses them to identify potential improvements;
- the Pedestrian Environment Data Scan (PEDS) tool (Clifton et al., 2007), which assigns quantitative scores to four sets of questions covering the categories of environment, pedestrian facility, road attributes and walking/cycling environment, in addition to a small number of subjective scores (attractiveness and perceived safety); and
- the Pedestrian Environment Review System (PERS) (Allen, 2005), which is the one selected for the present study and is outlined in more detail next.

2.2. The Pedestrian Environment Review System (PERS) methodology and tool

PERS has been developed in the UK by the Transport Research Laboratory (TRL) (Allen, 2005). Implementing a three-tier system, where each level offers a more detailed assessment of the previous level (Tier 1: Public space -> Tier 2: Route -> Tier 3: Link, Crossing), PERS is based on the completion of a series of separate independent review forms. A wide range of parameters are covered by the review framework, relating to different aspects of urban design features.

Focussing on the evaluation of Tier 3 elements and the most fundamental elements of a street environment the following parameters are considered and rated in PERS when assessing the walkability of a link:

- *Effective width*, i.e. the space allocated to pedestrians in relation to reduced-mobility users, pedestrian flows, the allowance of obstructions and pedestrian congestion;
- *Kerb height*, assessed in relation to accessibility for pedestrians with reduced mobility;
- *Gradient*, i.e. the steepness of the pavement, distinguished between longitudinal and transversal;
- *Obstructions*, i.e. objects that can cause a deviation to pedestrians, which can be temporary or stationary;
- *Permeability*, i.e. the frequency and ability of pedestrians to cross a road;
- *Legibility*, i.e. the information that is given to pedestrians explicitly or implicitly so that they can orientate themselves in an urban environment;
- *Lighting*, i.e. the compliance with the minimum provision recommendations for street lightning;
- *Tactile information*, i.e. the provision and quality of objects helping the orientation of blind and partially-sighted, as well as cognitively-impaired pedestrians;
- *Colour contrast*, acting as a means of orientation and navigation of pedestrians;
- Personal security, i.e. the vulnerability to, or fear of, crime in relation to certain environmental features;
- *Surface quality*, i.e. the evenness and friction of a surface, assessed by the presence of trip hazards;
- *User conflict*, i.e. the level of adverse interaction of pedestrians with other users, such as cyclists or motorised traffic;
- *Quality of the environment*, i.e. the general ambience, recorded qualitatively as a function of several factors, such as the noise of traffic, aesthetics and quality of materials or private frontages; and
- *Maintenance*, i.e. the cleanliness, as well as the level of damage to the existing street furniture.

Similarly, the parameters considered and rated in PERS when assessing the walkability of a crossing include:

- *Crossing provision*, i.e. the existence of a crossing at a specific location and the suitability of its type with respect to its context and strategic function;
- *Deviation from the desire-line*, i.e. how pedestrians deviate from the direct distance line when using the crossing;
- *Performance*, i.e. the safety and effectiveness of the crossing;
- *Crossing capacity*, i.e. the provided crossing space for pedestrian flows;
- *Crossing time*, i.e. the time a pedestrian needs to cross as they deem safe and acceptable for a given situation;
- *Legibility*, i.e. the ease by which pedestrians can identify where to cross and drivers where to stop and/or be warned that a priority change might occur;
- *Tactile information*, i.e. the provision, quality and effectiveness of tactile paving, as well as the positioning of the push button at signal-controlled crossings;
- *Kerb height*, assessed in the same way as for links in relation to the accessibility for pedestrians with reduced mobility;
- *Gradient*, i.e. the steepness of the pavement at the crossing location, as for links, distinguished between longitudinal and transversal;
- *Physical obstructions*, i.e. the presence of features causing pedestrians to deviate from their intended paths, and the degree to which they do so;

Table 1
Parameter weights for Tier 3 elements in PERS (TRL, 2006).

Links		Crossings	
Parameter	Weight	Parameter	Weight
Effective width	5	Crossing provision	5
Dropped kerbs	3	Deviation from desire line	3
Gradient	1	Performance	5
Obstructions	3	Capacity	1
Permeability	3	Delay	3
Legibility	1	Legibility	1
Lighting	3	Tactile information	3
Tactile information	3	Dropped kerbs	3
Colour contrast	3	Gradient	1
Personal security	5	Obstructions	1
Surface quality	3	Surface quality	3
User conflict	5	Maintenance	1
Quality of the environment	1		
Maintenance	1		

- *Surface quality*, i.e. the evenness and smoothness of the surface, as assessed by a visual inspection; and
- *Maintenance*, i.e. the extent to which the crossing is litter- and/or leaf-free.

Auditors are required to assign scores between −3 and +3 to each of the parameters independently, according to relevant scoring charts that provide sample reference descriptions. A total score for each link or crossing is, then, calculated as the weighted average of the scores of the parameters. The values of the weights correspond to the importance of the parameters in the pedestrians' perceived utility (Clark and Davies, 2009) according to the factors given in Table 1. Overlaying the total scores for each link and crossing from PERS on a map enables the visualisation of the results, which offers a quick insight into the street space under analysis.

As part of this study, the PERS methodology is applied to the pedestrian network of a town in Luxembourg, and this allows for the evaluation of how well national highway standards reflect walkability aspects.

3. National context and application case study

This section provides a brief overview of the relevant Luxembourgish national transport policy and highway design standards, and introduces the study area.

3.1. National highway design standards

A study commissioned by the Ministry of Sustainable Development and Infrastructure of Luxembourg (MDDI) found that 60% of the trips shorter than 1 km are made by car (MDDI, 2012). Theoretically, all these trips could be made by walking, and so the national transport policy in Luxembourg is driven by a desire to change the behaviour of travellers by promoting "soft mobility" (walking and cycling) projects. In line with worldwide trends, the policy involves diverging from the traditional focus on private transport (vehicular traffic) and concentrating more on improving the pedestrian and cycling networks, as well as public transport. The target is to increase the share of soft mobility to 25% by 2020 and that of public transport to 19%, while at the same time improving the population's health and lowering the transport sector's carbon emissions.

In view of the national transport policy objectives, the road network of Luxembourg consists of roads of three categories: national roads; country roads; and local roads. National roads and country roads are mostly highways with higher traffic flows and speeds and are managed by the MDDI. Local roads, on the other hand, are located predominantly in residential areas and fall under the jurisdiction of the respective local authority (commune). Fig. 1 presents the classification of roads within urban areas. 1st Order roads are national roads regulated to 50 km/h. 2nd Order roads can vary between country roads and local roads regulated to 50 km/h with right priority rules, but may also be regulated to 30 km/h or 20 km/h if crossing residential areas. 3rd Order roads are local (commune-level) streets with low traffic flows and densities, usually regulated to 30 km/h or 20 km/h; 3rd Order roads are usually characterised by high levels of pedestrian activity, and include streets designed according to the concept of shared space, as well as fully pedestrianised zones.

The present study focuses mainly on the highway design standards for 3rd Order local streets, for which the primary objective is to ensure low traffic speed and make walking and cycling more attractive. In order to be able to draw comparisons with the PERS methodology, the aspects relating to links and crossings are presented separately.

Highway design standard aspects relating to links include the following concepts:

- *Zone 30 s*: these are local roads that are regulated to 30 km/h, and in which right-hand priority rules apply. The entrances of a zone need to comply with specific design features. Within these zones, parking is allowed along the kerbs, which should have a minimal kerb height of 3 cm and should supply a minimal footpath width of 2 m. No formal crossings

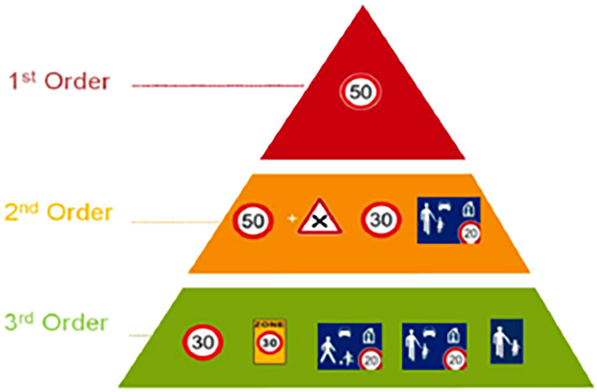

Fig. 1. Luxembourg national road hierarchy (MDDI, 2013).

are required so as to enable higher permeability, where pedestrians can chose where they like to cross rather than following specific crossing points. Exceptions to this are only made in front of schools and at places with particularly high pedestrian flows (MDDI, 2013).

- *Residential zones and shared spaces*: these have no specific footpaths for pedestrians and are considered as spaces where cars, pedestrians and cyclists can co-exist without any strict separation between them (Fig. 2). Residential zones are recommended to be located only on 3rd Order roads, whereas shared spaces can also be applied to 2nd order roads with higher densities. The higher safety level provided due to the stricter speed regulation and the reduced carriageway width aims to slow down the vehicular traffic to allow children to play on the street and consequently to improve the quality of life of the residents (MDDI, 2013).
- *Other zones*: to ensure accessibility of the street by all users, including pedestrians with physical or cognitive disabilities, it is recommended that: appropriate materials be used to ensure that the surface is not slippery, not glaring, and free from potholes or cracks wider than 2 cm; visual information be provided to indicate the separation of vehicle and pedestrian areas; access to crossings does not exceed a height of 3 cm or a gradient of more than 6%; and that a free passage of at least 1 m be guaranteed between buildings, obstacles and construction sites. Moreover, an absolute minimum footway width of 1.2 m should be provided at all times, with a recommended 1.8 m to be used wherever possible to achieve better walkability (MFSSJ, 2000).

Correspondingly, highway design standard aspects relating to crossings include the following concepts:

- *Vertical legibility*: crossings should be clearly signposted using the corresponding highway signage. They should also be adequately lit, following the guidelines of DIN 67523-1/2, such that a minimum luminosity of 30 lx and 4 lx is provided at the crossing centre-line and all external points respectively. Street lights are to be placed in such a way that they are clearly visible to pedestrians in all weather conditions (MDDI, 2014).

Fig. 2. Residential zone (left) and shared space (right) (MDDI, 2013).

- *Horizontal legibility*: national guidelines recommend the application of white paint in a transversal position to the footpath. The friction of the paint needs to be designed in a way that is not slippery for cyclists and vehicles at times of rain and snow. MDDI (2013, 2014) also requires the application of a red background to the white crossing paint at the entrances of residential areas and Zone 30 s in order to make drivers aware that they are entering a low-speed zone.
- *Safety distances*: MDDI (2014) recommends a minimum 5 m distance to be kept between crossings and other features (e.g. bus stops, junctions, etc.) to ensure sufficient visibility for both pedestrians and drivers. MDDI also recommends avoiding the positioning of the crossing on a curve. For more detailed guidelines on safety distances, the relevant German highway design standard is used (FGSV, 2008), which recommends safety sightline distances in relation to contextual and geometric characteristics, such as traffic speed and the slope of the road.

3.2. Study area

The chosen study area in this work is the commune of Lorentzweiler (Fig. 3), which is located in the central part of Luxembourg's territory. It is a rural/sub-urban area of 17.5 km^2 and has a population of 3531, consisting of six towns: Asselscheuer, Blaschette, Bofferdange, Helmdange, Hünsdorf and Lorentzweiler itself. The area is located between two major employment centres of the country: the city of Luxembourg and the city of Diekirch (Statec, 2014), which makes it a particularly relevant case study to analyse, as pedestrians do not use the local infrastructure only for leisure, but also on a daily basis for commuting.

The area includes links and crossings that are forming the pedestrian routes to bus stations, school buildings, retirement centres and other points of interest. The local road infrastructure consists of a 1st Order national road passing through Lorentzweiler and carrying high traffic flows, as well as 2nd Order roads connecting the main attraction points. The commune has recently introduced Zone 30 s to the area's local streets, as well as one residential zone (20 km/h). One major attraction point of the area is the train station, which allows commuters to access the public transport links to the major employment hubs of Luxembourg City, Mersch and Diekirch.

The commune of Lorentzweiler is used as a case study for the application of the PERS methodology at the network level and the comparison of the results with the highway design standards. This is reported in the next section.

4. Evaluation and analysis

The section consists of two parts. In the first part the PERS methodology is applied to the network of the commune of Lorentzweiler in order to evaluate the walkability of its links and crossings. This is then compared with the Luxembourgish highway design standards in order to assess how well the standards reflect walkability and to identify potential improvements.

4.1. Walkability assessment using PERS

A large-scale walkability assessment of the road network of the commune of Lorentzweiler is carried out, whereby the PERS methodology is applied to a total of 52 links and 53 crossings. The assessment is carried out by a single expert auditor,

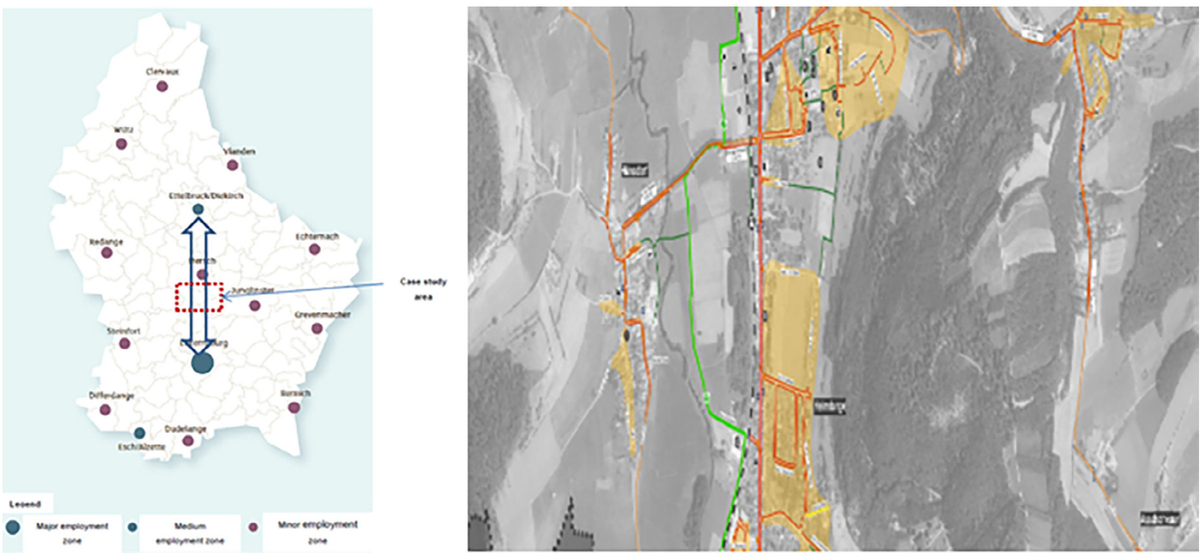

Fig. 3. Location and map of the commune of Lorentzweiler (adapted from MDDI, 2012).

having received relevant self-training by studying the PERS manual in advance. For each link and crossing, a weighted average score of the walkability is obtained on PERS's defined scale of −3 to +3 and using the weights shown in Table 1, where highly positive values denote good walkability (+1 to +3), values around 0 indicate neutral walkability (−1 to +1), and highly negative values translate to insufficient walkability (−1 to −3). The results of the PERS assessment of all links (longitudinal network) and crossings (transversal network) are shown in Fig. 4, where Red-Amber-Green (RAG) bands are used to denote ratings. The results are presented in tabular form, whereby the aggregated average rating for each link and crossing is shown in the cells of the last row of each table, while the aggregated average rating for each of the PERS evaluation parameters across all links and crossings surveyed is provided in the cells of the last column of each table. The aggregated average scores for each of the parameters in the links' and crossings' evaluation across the whole network are also given in the diagrams of Figs. 5 and 6 respectively.

Looking first at the results of the links' assessment (Fig. 4), it can be seen that in 20 out the 52 links the walkability score is rated as "good" (green), while in the remaining 33 links it is rated as "neutral" (amber). It is also notable that there appears to be a positive correlation between walkability scores and Zone 30 links, where speeds are lower. With respect to the crossings, 29 out of the 53 obtain a "good" (green) walkability score, while the remaining 24 are rated as "neutral" (amber). On none of the links or crossings is the total walkability found to be insufficient "insufficient" (red).

Considering the results of the links' assessment from the perspective of the individual parameters (Fig. 5), some interesting trends can be observed. Specifically, high scores are obtained for the parameters of "personal security", "lighting", "legibility", "permeability" and "maintenance", while particularly low scores are recorded for the "colour contrast" and the "effective width" parameters. In the case of "colour and contrast", the score can be attributed to the fact that in PERS this is assessed both in terms of the contrast between the footpath and the carriageway, but also between the footpath and the street furniture. This is a walkability parameter that is not considered by the highway design standards, and as a result, it may often be omitted. As concerns the low score in the "effective width" parameter, this is mainly due to the generally narrower than recommended footpaths provided in the area (usually less than 1.5 m, and sometimes even less than 1 m), which often forces pedestrians to use the carriageway to continue their journey. This is further exacerbated by the presence of temporary obstructions (parked cars, rubbish bins, untrimmed hedges) on the footpaths, in particular in the vicinity of crossings where dropped kerbs are provided.

Looking then at the results of the crossings' assessment from the perspective of the parameters (Fig. 6), generally high scores are reported for "crossing capacity", "delay", "gradient", "surface quality" and "maintenance", while "obstructions" and "legibility" obtain lower scores, and the "sensory impaired legibility" parameter (or "tactile information") obtains an "insufficient" rating across the entire network. The reason behind this is the observation that in the vast majority of the crossings reviewed there has been absence of tactile materials altogether, which is expected, as there is no such requirement in the highway design standards. As concerns the other low ratings, "legibility" can be explained by the fact that many of the crossings have insufficient lighting provision, while "obstructions", again, can be attributed to the presence of parked cars on the footway.

4.2. Assessment using highway design standards

Having carried out a network-wide walkability evaluation in the road network of the commune of Lorentzweiler, it is now possible to perform an assessment of how well the national highway design standards reflect walkability principles and how they could be revised to better incorporate them. As a whole, based on the results, it can be concluded that the Luxembourgish highway design standards achieve good levels of walkability. It is notable that in all links and crossings of the network, "good" and "neutral" walkability ratings are obtained. However, there are some areas of clear under-performance of the standards from a walkability perspective, as some parameters appear to be inadequately considered, resulting in lower levels of walkability.

Firstly, Luxembourgish national standards and legislation currently make no provision (mandatory or optional) on colour and contrast of street spaces. This, however, is a factor that could greatly contribute to the walkability of an area, and so it is recommended that a relevant section is added in the national guidelines so as to improve the perceptions of pedestrians. In particular, it is recommended that further research is carried out in order to identify suitable colour combinations that could improve walkability.

Furthermore, the results of the case study have identified obstructions, such as parked cars, rubbish bins and untrimmed hedges, to be a particular issue affecting walkability, as they often make the already narrow footpaths even narrower. It is, hence, advisable to revise the minimum and recommended widths in the national guidelines so as to account for obstructions placed on the footway on a regular basis. Specifically, it is recommended that the minimum required width is increased to 2 m and the desirable width to 2.25 m. This is not a newly identified issue, as in the most recent guidelines of MDDI (2013) a width of 2 m is already recommended, but as the PERS analysis shows, this is often not adhered to. Another solution could be to increase the kerb height in order to discourage footway parking, and evidence from the nearby commune of Luxembourg City suggests that, indeed, this could have an effect. However, it should also be taken into account that higher kerbs could also act as an obstacle to pedestrians with reduced mobility and may therefore actually worsen walkability. It may be, hence, better to look for "soft" operational solutions rather than "hard" design ones, such as the stricter enforcement of footway parking.

Fig. 4. Walkability assessment of each of the links (top) and crossings (bottom) in the commune of Lorentzweiler.

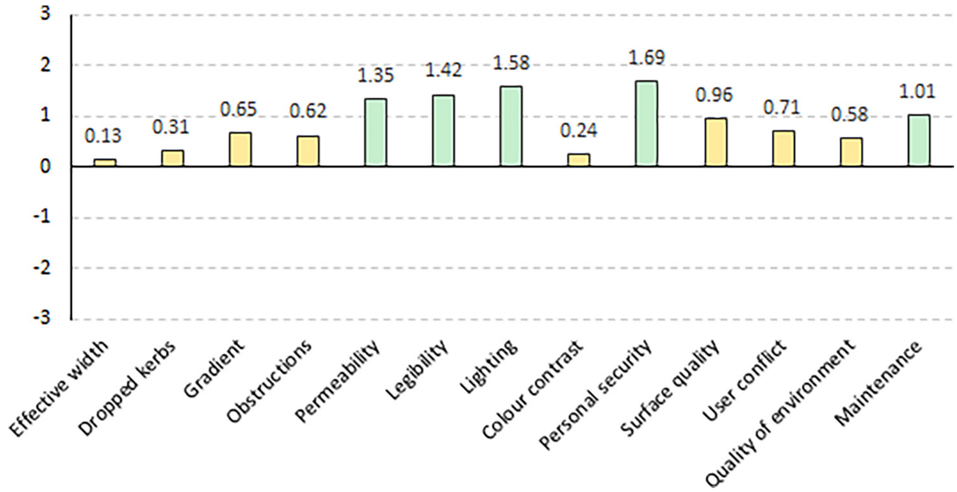

Fig. 5. Walkability parameter scores for links in the commune of Lorentzweiler.

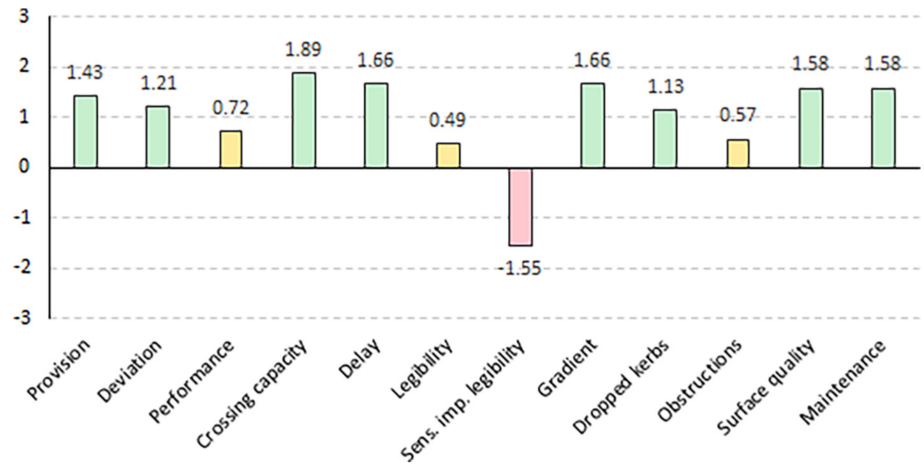

Fig. 6. Walkability parameter scores for crossings in the commune of Lorentzweiler.

Moreover, the PERS analysis has highlighted that the vast majority of the crossings reviewed lack tactile information, and this has resulted in very low scores for the relevant parameter. In order to be able to provide a coherent and inclusive pedestrian network accounting for the needs of visually-impaired pedestrians, tactile information should be installed at all crossings in the near future, and this should be regulated accordingly in the standards, which, currently make no provision for it.

Another parameter identified by the PERS analysis is the gradient, which, even though for the network as whole, has obtained a "good" score, is rated as "insufficient" in several individual links due to topographical features. The gradient plays an important role for elderly and mobility-impaired pedestrians and is a factor directly affecting walkability, but currently highway design standards do not seem to be taking it into account. Improvements in this aspect could be delivered, for example, by providing rest points and seating, and it is recommended that such provisions are made in the design guidelines.

A further parameter deserving attention is the quality of the environment for links, which, despite having been rated as "neutral" at the network-level, exhibits significant variability between links, with the vastly "good" scores reported in Zone 30 links being counterbalanced by several "insufficient" ratings on footways located adjacent to national and country roads. This is due to the higher traffic densities and the corresponding pollution and noise, and is, naturally, exacerbated by the narrow footpaths. It is expected that the proposed revision of the recommended footway width will improve this aspect, but additional measures could also be introduced in the guidelines, such as, for example, the provision of landscaping to reduce noise and protect pedestrians from splashing water.

Finally, the PERS study has found that Zone 30 s can generally achieve a better pedestrian environment due to their ability to reduce traffic speeds. In new development areas, where widths of streets can be designed according to requirements, the implementation of Zone 30 s with a 2 m to 2.2 m footway width is feasible. For existing street layouts, however, with narrower road widths, a re-design from a traditional street design to a residential zone can improve walkability.

5. Conclusions

In this study the disparity between good design for pedestrians and highway design standards has been assessed. Using the road network of the Luxembourgish commune of Lorentzweiler as an example, a large-scale network-level walkability assessment by means of the well-established PERS methodology has been carried out and the findings have been compared with existing national highway design standards. The results suggest that, in general, the standards achieve good levels of walkability, but also that there are some clear areas of under-performance, where appropriate revisions would be useful. Examples include the introduction of colour contrast, the increase of the minimum and recommended footway widths, and the provision of tactile materials and information at crossings.

While the present study has thrown some light into the topic of addressing walkability in highway design standards, research in this direction continues. Further work will primarily concentrate on collecting data from more sites and countries in order to investigate similarities and differences with the case of Luxembourg and to be able to extract more generic conclusions. Additionally, a similar activity will be carried out with respect to cyclists, such that it can be evaluated how well design standards address their needs. Finally, the work will extend into the field of road user behaviour, and through the development of appropriate primary data collection means and relevant models, it will be investigated how the suggested revisions to the standards are likely to affect perceptions.

Acknowledgements

The authors would like to thank the Commune of Lorentzweiler and Schroeder & Associés S.A., and in particular Dipl.-Ing Jean-Luc Weidert, for their contribution to this study.

References

Aghaabbasi, M., Moeinaddini, M., Zaly Shah, M., Asadi-Shekari, Z., 2017. A new assessment model to evaluate the microscale sidewalk design factors at the neighbourhood level. J. Transp. Health 5, 97–112.
Allen, D., 2005. PERS v2: auditing public spaces and interchange spaces. Walk21-VI "Everyday Walking Culture". In: The 6th International Conference on Walking in the 21st Century.
Atkins Intelligent Space, 2008. Oxford Street VIP Day 2007. Report for Transport for London by Atkins Intelligent Space.
Boarnet, M.G., Day, K., Alfonzo, M., Forsyth, A., Oakes, M., 2006. The Irvine-Minnesota inventory to measure built environments: reliability tests. Am. J. Prev. Med. 30, 153–159.
Clark, S., Davies, A., 2009. Identifying and prioritising walking investment through the PERS audit tool. Walk21 IX. In: 10th International Conference on Walking and Liveable Communities.
Clifton, K.J., Livi Smith, A.D., Rodriguez, D., 2007. The development and testing of an audit for the pedestrian environment. Landscape Urban Plann. 80, 95–110.
Day, K., Boarnet, M., Alfonzo, M., Forsyth, A., 2006. The Irvine-Minnesota inventory to measure built environments: development. Am. J. Prev. Med. 30, 144–152.
Emery, J., Crump, C., Bors, P., 2003. Reliability and validity of two instruments designed to assess the walking and bicycling suitability of sidewalks and roads. Am. J. Health Promotion 18, 38–46.
Evenson, K.R., Sotres-Alvarez, D., Herring, A.H., Messer, L., Laraia, B.A., Rodríguez, D.A., 2009. Assessing urban and rural neighborhood characteristics using audit and GIS data: derivation and reliability of constructs. Int. J. Behav. Nutr. Phys. Act. 6, 44.
FGSV, 2008. Richtlinien für die Anlage von Stadtstraßen. FGSV Verlag, Köln, Germany.
Forsyth, A., Oakes, J.M., Schmitz, K.H., 2009. Test-retest reliability of the twin cities walking survey. J. Phys. Act. Health 6, 119–131.
Galanis, A., Eliou, N., 2011. Evaluation of the pedestrian infrastructure using walkability indicators. WSEAS Trans. Environ. Dev. 7, 385–394.
Galanis, A., Eliou, N., 2012. Development and implementation of an audit tool for the pedestrian built environment. Transport Research Arena – Europe 2012. Procedia – Social Behav. Sci. 48, 3143–3152.
Kihl, M., Brennan, D., Gabhawala, N., List, J., Mittal, P., 2005. Livable Communities: An Evaluation Guide. AARP Public Policy Institute.
Mercieca, J., Kaparias, I., Bell, M.G.H., Finch, E., 2011. Integrated street design in high-volume junctions: the case study of London's Oxford Circus. In: 1st International Conference on Access Management.
MDDI, 2012. MODU, Stratégie globale pour une mobilité durable. Le gouvernement du Grand-Duché de Luxembourg, Luxembourg.
MDDI, 2013. Apaisement du trafic à l'intérieur des agglomérations. Ministère du Développement durable et des Infrastructures (MDDI), Luxembourg.
MDDI, 2014. Passages pour piétons en agglomération. Le gouvernement du Grand-Duché de Luxembourg, Luxembourg.
MFSSJ, 2000. Guide des Normes. Luxembourg: Info – handicap a.s.b.l.
Pikora, T., Jamrozik, K., Knuiman, M., Giles-Corti, B., Donovan, R., 2002. Developing a reliable audit instrument to measure the physical environment for physical activity. Am. J. Prev. Med. 23, 187–194.
Saelens, B.E., Sallis, J.F., Black, J.B., Chen, D., 2003. Neighborhood-based differences in physical activity: an environment scale evaluation. Am. J. Public Health 93, 1552–1558.
Sarkar, S., 1993. Determination of service levels for pedestrians with European examples. Transp. Res. Rec. 1405, 35–42.
Statec, 2014. Les communes et les cantons du Luxembourg dans le miroir du recensement de la population. Edition Saint-Paul, Luxembourg.
Talen, E., 2008. Pedestrian access as a measure of urban quality. Plann. Pract. Res. 17, 257–278.
TRL, 2006. Pedestrian Environment Review System. TRL Ltd., London.
Troped, P.J., Cromley, E.K., Fragala, M.S., 2006. Development and reliability and validity testing of an audit tool for trail/path characteristics: the Path Environment Audit Tool (PEAT). J. Phys. Act. Health 3, S158–S175.
Vernez-Moudon, A., Lee, C., 2003. Walking and bicycling: an evaluation of environmental audit instruments. Am. J. Health Promotion 18, 21–37.