Disabled-by-Design: Effects of Inaccessible Urban Public Spaces on Users of Mobility Assistive Devices – a Systematic Review

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Abstract

Purpose: Despite the increase of users of Mobility Assistive Devices (MobAD), there has been a lack of accessibility in urban environments in many parts of the world. We present a systematic review on how inaccessible design of public spaces affects quality-of-life – including aspects of health and safety, independence, and social participation – of MobAD users.

Materials and methods: We conducted a literature search in three databases (i.e., Scopus, Web of Science, and PubMed) and initially discovered 3980 publications. We analysed 48 peer-reviewed journal articles published in English from 2005 till 2021 and assessed their quality of evidence via the Mixed Methods Appraisal Tool.

Results: Findings indicated a substantial number of inaccessible elements for MobAD users in public spaces. Pathway characteristics, boarding ramps, entrance features, confined spaces, and service surfaces were deemed to be the least accessible elements. These barriers had multifaceted effects on MobAD users' quality-of-life with aspects of physical health, mobility, and use of public transport being most affected.

Conclusions: Notwithstanding that the reviewed studies mostly focused on wheelchair users residing in high-income countries, this review outlines the critical role of the design of the built environment as a factor of disablement for MobAD users. We conclude by highlighting a few recommendations for future research and practice, especially inclusive approaches and adaptive techniques to assist MobAD users with performing tasks in public spaces independently.

Keywords

accessibility; public spaces; quality of life; mobility assistive devices; disability; barriers; review

1. Introduction

Disability has been an ever-present and complex phenomenon in the history of human civilisation [1]. It is a condition that can significantly affect the quality of life of individuals, namely their health and well-being, functioning capabilities, and participation in society [2,3]. Mobility impairments lead to considerable disruptions in functioning [4], especially the ability to freely and easily move between places temporarily or permanently. Mobility impairments can occur due to multiple conditions, including – but not limited to – arthritis and leg fractures. Mobility-related impairments are amongst the most common types of impairments worldwide, with approximately 25% of all impairments considered mobility-related [5–7].

On many occasions, assistive technologies have been implemented to support people with mobility impairments to maintain, facilitate, and improve their everyday activities [8]. Wheelchairs, scooters, and ambulatory assist devices (such as canes, crutches, and walkers) are examples of mobility assistive devices (MobAD) that have provided their users with a varying degree of autonomy and enhanced their participation in local communities [9]. Notwithstanding the contribution of assistive devices, existing societal barriers (e.g., stereotyping and prejudice) or physical obstacles in the built environment can be insurmountable challenges for their users [10–12]. This review focuses on the impact of inaccessible public spaces in the built environment on health, independence, and social participation of MobAD users.

1.1. Public spaces

Public spaces provide the spatial context for community activities such as transport, recreation, and retail [13]. Carmona [14] describes public spaces "*as the focus for public life, activities and events*", which can "*range in form from informal street corners to grand civic* *set pieces*". Urban public spaces can be open, such as parks, squares, or sidewalks, or they can be built-up areas, such as libraries or other public service buildings, which people use in cities [15]. The division between public and private uses is not always discernible in the public realm, especially across dense urban environments [16,17]. For instance, several urban theorists regard sidewalk cafés and restaurant courtyards as indispensable parts of vibrant public spaces [18,19]. Even privately-owned areas that attract the public interest – such as shopping malls, fitness centres, and art galleries – are eventually utilised and perceived as parts of the public realm [20].

Each public space possesses macro-, meso- (middle), and micro-environments – separate scales that interlink or overlap to form the whole [21]. The *macro-environment* includes the largest scale infrastructure, for instance transport areas, site or building approach, horizontal and vertical circulation, and service areas for the public such as picnic areas or cinema halls. The *micro-environment* involves the smallest scale considerations, such as street furniture, floorings, doors, and stairs. The *meso-environment* falls between the largest and smallest built elements, for example including sidewalks, entrances, parking spaces, and building corridors. Despite their typological or structural variations, a central norm of all public spaces should be that all members of the community have access to them by right or invitation [16,22]. Testing the vision of universal access, this review focuses on MobAD users and their (in)ability to access public spaces and their constituent elements, which affects their quality of life.

1.2. Quality of life

Quality of life (QoL) expresses life aspects that contribute to a sense of security, physical and emotional well-being, engagement, freedom, control, and choice [23]. There are many factors, facets, frameworks, and concepts to clarify and organise its meaning [24]. The World

Health Organisation (WHO) distinguishes six main domains in measuring QoL of individuals: physical health, psychological state, level of independence, social relations, interaction with environment, and spirituality/religion/personal beliefs as the domains of quality of life of individuals [25]. This review examines how physically non-accessible public spaces can affect basic aspects of the QoL of MobAD users, namely their health and safety, independence, and social participation.

1.2.1. Health and safety

Physical and emotional health and safety are primary indicators of QoL [25]. Within the field of public health, there is a mounting realisation that the built environment has substantial impacts on personal health and safety [26,27]. Examples of health and safety issues of MobAD users related to urban design include physical factors in tips-and-falls as well as contributors to obesity such as neighbourhoods with limited food retail.

1.2.2. Independence

Independence is the ability of people to perform activities and tasks autonomously [4]. Research from the fields of human factors and ergonomics has proven that the way an artifact is designed has a strong influence on the independence of its users [28,29]. Similarly, design of public spaces can increase or diminish independence of the urban population. For instance, absence of handrails in public restrooms may limit the functional performance of mobility-impaired people.

1.2.3. Social participation

Participation in society and everyday activities – including transport, education, employment, political and public life, and healthcare – is a fundamental human right [30]. This is also true for facilitators of social participation, such as transport infrastructure. The Convention on the

Rights of People with Disabilities supports the right of all individuals to "*full and effective participation and inclusion in society*" [31]. Physical accessibility of public spaces can accommodate disabled people with participating in society and performing everyday activities [8,21]. For instance, provision of automatic doors in transport hubs can allow MobAD users to experience fewer physical barriers when using public transport.

1.3. Purpose & contribution

Several reviews have recently explored the level of physical accessibility of public spaces for MobAD users [32,33]; the impact of inaccessible public spaces on MobAD users [34,35]; or both topics [36,37]. However, most of these attempts solely focused on individual types of public spaces – such as transportation facilities [32], public buildings [33], and natural open spaces [34] – or even special features of the micro-environment of public spaces, e.g., sidewalk cross-slopes [35]. Other reviews were not characterised by a systematic methodological approach [33,36]. Although one review was particularly enlightening on addressing the level of physical accessibility of public spaces for MobAD users as well as the impact of inaccessible public spaces on MobAD users [37], it only focused on physical environments close to MobAD users' homes. That is, it did not encompass uses and spaces across the urban public realm. Moreover, the same review discussed effects of inaccessible spaces on users' mobility and community participation but omitted possible effects on other aspects of independence – for instance, reach capability – as well as health-related impacts.

In the context of existing knowledge, the rationale for this review can be found on two research gaps that remain. Firstly, no pieces of academic work have evaluated existing literature on the level of physical accessibility of public spaces for the entirety of the urban environment – i.e., public open spaces and buildings of public interest in a city-wide context. Secondly, only a few reviews have been undertaken on the relationship between physical accessibility and aspects of QoL. Indeed, most of those have only focused on mobility and activities of daily living, namely shopping and use of public transport.

In order to address the aforementioned gaps, this review scrutinises physical elements of both *open spaces and buildings* in the *urban public realm* to provide aggregated findings regarding accessibility for MobAD users. Our review also discusses possible repercussions of inaccessible public spaces through a wider range of *quality-of-life* aspects, including physiological condition, recreation, and educational opportunities. Additionally, we provide recommendations on *inclusive approaches and adaptive techniques* for future, high-quality research and practice to ameliorate the impact of physical barriers on MobAD users.

2. Materials and methods

We performed a systematic review of research to compile a list of the most obstructing physical barriers for MobAD users in public urban spaces and investigate the effects of inaccessible public urban spaces on the quality of life of MobAD users.

Systematic reviews use explicit, systematic methods to identify, select, and critically appraise relevant research. These methods are applied to minimise bias, thus providing more reliable findings from which conclusions can be made [38]. To adhere to the aforementioned standards, we adopted the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines[39], which comprises of (1) the clarification of research topic, (2) the selection of data sources, (3) the identification of search words (or, search strategy), (4) the application of eligibility criteria and, (5) selection of studies , (6) the assessment of methodological quality, and (7) data extraction.

2.1. Data sources and search strategy

We selected the following information sources: *Scopus Database, Web of Science Database* and *PubMed Database*, considering them particularly congruent to the three thematic review axes of "mobility assistive devices", "public spaces OR (constituent) physical elements", and "quality of life". Our search includes papers published between January, 2005 and December, 2021.

To access relevant articles, we searched in title, abstract, and keywords fields using combinations of English-language terms related to MobAD users (e.g., mobility device, wheelchair, walking cane, pushchair, stroller, mobility impaired), quality of life (e.g., access, health, wellbeing, safety, daily activity/tasks, comfort, fatigue, pain), and physical elements (e.g., pathway, sidewalk, pavement, ground surface, curb ramp, entrance, door, corridor, stair, public space). Terms for "physical elements of public spaces" and "quality of life" were identified with the help of the *American with Disabilities Act Accessibility Guidelines - ADAAG* [40] and the *World Health Organisation Quality of Life Assessment Tool - WHOQOL* [25]. The final terms we used are all shown in table 1 of the Appendix section, organised according to the three review axes – namely, MobAD, quality of life, and physical elements.

2.2. Eligibility Criteria

We collected and reviewed quantitative and qualitative journal peer-reviewed publications if they were written in English, published between January, 2005 and December 2021, reported the results of original research, and investigated MobAD-accessibility of the urban built environment or impact of physical barriers on aspects of QoL of MobAD users.

We omitted articles that referred to any types of the built environment other than spaces of public interest, as per ADAAG directions. ADAAG categorises public spaces into eight macro-environments, according to their functions: building blocks, accessible routes, general site and building elements, plumbing elements and facilities, communication elements and features, special rooms/spaces/elements, built-in elements, and recreation facilities. Each macro-environment consists of meso- and micro-environments that refer to different constituent elements of public spaces, for instance “walking surfaces” is a subcategory of the “accessible routes” macro-environment. Elements not referring to physical infrastructure or public spaces were also omitted in this review. The boarding ramp, which could be considered both physical and non-physical infrastructure, was included due to its significance to MobAD users.

Articles that investigated impacts of physical inaccessibility but did not refer to aspects of QoL were not included in this review. We used the WHOQOL tool as a reference point. Specifically, the WHOQOL tool distinguishes physical and psychological health, level of independence, social relationships, environment, and spirituality/religion/personal beliefs as aspects of quality of life of individuals. Studies that did not focus on any those aspects were excluded.

We also omitted studies that did not refer to users of MobAD (i.e., manual or powered wheelchairs, mobility scooters, canes, crutches, walkers, and strollers. Articles with a purely medical focus or on different thematic topics (e.g., MobAD mechanics) were excluded, too. Lastly, papers that could not be retrieved through the library of the authors' respective institutions were excluded.

2.3. Study Selection

Two investigators independently screened all titles resulting from the electronic searches. Those titles of interest were imported into the Mendeley reference management software (Version 1.19.5; Elsevier, 2019) to remove duplicates, and then the remaining abstracts were reviewed. After excluding papers not meeting the review’s inclusion criteria, the two investigators independently reviewed the full papers of all remaining studies. A backwardforward citing analysis was conducted on selected publications (i.e., exploration of references and citations of each article) to cover their thematic scope, which led to selecting additional publications. Disagreements on papers to exclude at all stages were resolved through discussion with a third investigator. See figure 1 for an account of the selection process, which details the number of papers included/excluded at each step, and reasons for the exclusion of papers.

2.4. Assessment of methodological quality

The peer-reviewed *Mixed Methods Appraisal Tool* (MMAT) was used to assess the quality and strength of evidence presented in the included articles. The MMAT, already used by more than 100 systematic reviews, is designed for systematic reviews that include qualitative, quantitative and mixed-methods studies. It allows the use of one tool for concomitantly appraising the most common types of empirical studies [41]. Each included study is rated in its appropriate methodological category, namely mixed methods, qualitative, quantitative, which are subdivided into three sub-domains: randomised controlled, nonrandomised, and descriptive. Category criteria[1] generally refer to data collection methods, data analysis strategies, risk of bias, sampling, confidence, and methodological consistency [41], and are rated either “yes”, “no” or “can’t tell”.

Two authors of this review conducted the methodological quality assessment independently. In case of disagreement, the third author of the review intervened as a mediator and consensus was achieved through general discussion. For every met criterion (i.e., rated as “yes”), the examined article was given one star, resulting in a possible

[1] For more detailed explanations on the category criteria and variations between them, please refer to http://mixedmethodsappraisaltoolpublic.pbworks.com/.

maximum 5-star rating. Articles that received less than three stars were regarded as obscure in terms of methodological quality and thereby excluded from the review.

2.5. Data extraction

A unique coding scheme was created to extract information from the reviewed articles in relation to the objectives of this review. The qualitative data analysis computer software NVivo (Version 11.0; QSR International, 2020) was used to code the articles according to (a) article characteristics (author, year of publication, country, methodological approach, quality of evidence), and (b) objective-related insights (purpose, main findings).

Two authors of this review were responsible for building the coding scheme. In case of disagreement, the third author of the review intervened as a mediator and consensus was achieved through general discussion. Some codes, particularly those concerning objective-related insights, were further divided into sub-categories to gain analytical understanding of the studied subject and help with synthesising the review findings. Table 2 of the Appendix section presents the coding scheme and created codes per class of information.

3. Results

The electronic database search resulted in 3980 papers. Of these papers, 936 abstracts were reviewed, and subsequently 87 articles were selected to read in their entirety. After reading these papers, 42 were excluded, resulting in 45 articles. Another 7 articles were added to those, after a backward- and forward-citing process. After assessing those 52 papers in terms of methodological quality, 4 articles were found to be of substandard quality and excluded from this review. Consequently, we included 48 articles in this review. The flow diagram in Figure 1 has been constructed according to PRISMA guidelines and identifies the numbers of papers excluded at each stage, and reasons for their exclusion.

[Figure 1 – please see appendix]

The results are structured around the coding scheme of Section 2.4 – Data Extraction. Table 3 of the Appendix section briefly summarises the collected content according to the seven main codes of the coding scheme. Specifically, it includes an aggregated analysis of the 48 reviewed articles, listed alphabetically, in relation to their publication details, purpose and types of MobAD examined, methodological approach, quality of evidence, and key findings.

3.1. Characteristics and quality of selected articles

The review included 48 articles published from 1.1.2005 until 31.10.2021, of which over 50% were published during 2015 and 2021. A quarter of these articles were published in 2019 and 2020 (6 apiece). Those are indicators that research in the area is growing.

Approximately 3 out of 4 studies were carried out in high-income countries of the Global North. Most studies were conducted in the United States (14), followed by Canada (8), and Sweden (4). Regarding the types of MobAD examined, wheeled devices (e.g., manual and power wheelchairs) far outnumbered devices that support the activity of walking (e.g., canes and crutches). These data show that the collected literature was not equally distributed in terms of demographics.

In terms of thematic relation to the main purpose of this review, 8 articles focused on physical accessibility assessments. Another 25 articles reported effects of physical elements on QoL of MobAD users. The remaining 15 articles focused on both themes. These data imply that quality of life is a dominant theme, as it was addressed by over 80 per cent of the selected studies.

The majority of the reviewed content (21 studies) employed a descriptive research approach in the sense that they primarily focused on describing what physical barriers exist in the built environment. More than half of the studies (24) utilised quantitative data analysis methods. Regarding data collection techniques, social surveys (in 17 studies) and personal interviews (in 15 studies) were adopted most frequently. Those are indicators that most studies directly involved human participants (i.e., MobAD users) to provide conclusions and influence decision-making regarding the the phenomenon of physical inaccessibility.

Quality of evidence of the reviewed articles was assessed using the MMAT. 39 studies met with over 80% of the MMAT Criteria, while 15 therein met with 100%. Therefore, the majority of the reviewed content deemed to be of substantial quality. Study limitations was the primary factor for quality shortcomings. Low sample representativeness was the most recurrent limitation as mentioned in 20 studies. In most of these cases, the full range of MobAD users was not represented or the sample size was too low. This means that results of those studies should be used with caution before generalised.

3.2. The impact of inaccessible public spaces on life aspects of users of Mobility Assistive Devices

Reviewed studies that assessed accessibility of public spaces indicated a substantial number of problematic elements for MobAD users. We categorised these elements in four macro-environments – i.e., outdoor environments, transport physical facilities, building approach, and indoor facilities – according to their spatial location and function. We then examined their impact on QoL aspects of MobAD users.

3.2.1. Outdoor environments

Inaccessible pathways monopolised the research interest with respect to outdoor environments. This can be attributed to the fact that many disabled people find their journeys outdoors interrupted at the very first stage – the sidewalk. Figure 2 summarises the impact of pathway characteristics on various QoL aspects for MobAD users.

[Figure 2 – please see appendix]

3.2.1.1. Problematic pathway characteristics – a source of safety hazards and health maladies. Numerous studies indicated that pathway characteristics – namely narrow, rough, uneven, or sloped sidewalks – were key factors for limited MobAD-accessibility outdoors [42–50]. The large volume of research that has been dedicated to problematic pathway characteristics underscores their significance with respect to urban accessibility.

Safety of MobAD users was mostly challenged by physical barriers in pathways. Specifically, Chen et al. [51] concluded that wheelchair-related accidents, predominantly tips-and-falls, were frequently caused by narrow, rough, or uneven pathways. These types of accidents could cause minor, moderate, severe or even fatal injuries to users of power mobility wheelchairs and scooters, as Carlsson and Lundalv [52] indicated. Despite the fact that Carlsson and Lundalv [52] only investigated injuries resulting from accidents involving powered mobility devices, we can presume that these findings apply on – perhaps with lesser propensity – users of manual wheelchairs as well. These findings suggest that appropriate replacement or further development of physical infrastructure – for instance, lowering curbs – would contribute to increased safety and navigation for MobAD users.

Fatigue and physical pain due to pathway characteristics was another issue studied by researchers. Pierret et al. [53] suggested that pathway cross-slopes – i.e., slopes perpendicular to the direction of travel – exceeding a critical threshold (i.e., 8%) could impose noteworthy cardio-respiratory strain on users of manual wheelchairs. Despite the importance of these findings, fatigue is a highly subjective parameter and a function of several user attributes such as the nature of the disability, physical and mental fitness, and MobAD characteristics. That is, further work is needed to confirm the impact of pathway cross-slopes on the physiological condition of MobAD users as a whole.

Outdoor walking surfaces with wide and frequent cracks – such as brick sidewalk surfaces – subjected wheelchair users to harmful whole-body vibrations, which could be associated with increased health risks such as pain in the back and neck as well as muscle fatigue, according to Duvall et al. [54]. The core value of the previous study derives from its findings, which were used to develop a meaningful standard for surface roughness to augment existing accessibility guidelines (i.e., ADAAG 2010). Similarly, Hurd et al. [55] reported that rough materials used for paving – such as aggregate concrete – could considerably increase body fatigue levels for users of manual wheelchairs. The previous two studies seem to agree that some widely used paving techniques are inappropriate for MobAD users' physical condition. Their findings are significant sources for infrastructure planners, engineers, and urban designers are to understand the implications of these terrain characteristics for MobAD users.

Tactile paving or Tenji blocks, which are used internationally to provide location and directional information at crosswalks to blind pedestrians, could be impede the smooth navigation of MobAD users. Specifically, these types of tactile guides were found to inflict fatigue and increase instability for people using a wide range of MobAD – especially due to uneven surfaces perpendicular to the direction of travel [56]. The case of Tenji blocks typifies a clash of accessibility provisions between two special interest groups. This is because an accessibility facilitator for visually impaired individuals was deemed to be a barrier for MobAD users. A possible solution for city professionals would emerge through parallel trials where researchers could compare crossing behaviour of both groups [56]. Outcomes from these studies could provide scientific basis for performance-driven crosswalk design patterns, which would universally cater for both visually impaired and mobility-impaired people according to their functional capabilities.

3.2.1.2. Safety concerns and subordinate effects due to inaccessible pathways. Safety fears as a direct result of problematic pathway characteristics had spill-over effects on MobAD users' independent navigation. Cross-sloped sidewalks exceeding accessibility thresholds made it challenging for users of manual wheelchairs to safely navigate over sidewalks [42]. Moreover, curb ramps – which failed to meet accessibility guidelines – entailed the risk of MobAD users tipping over or being struck by road traffic [57]. For Bromley et al. [58], lack of curb ramps maximised inconvenience in independent navigation of MobAD users in a city-centre environment. Another study by Khalili et al. [59] showed that safety concerns due to non-uniform or rough terrains – such as gravel-made sidewalks or grassy pathways – was the primal impediment to MobAD users' manoeuvrability outdoors. An interesting remark derives from Prescott et al. [60], who highlighted the role of street infrastructure as a barrier to independent navigation. Specifically, excessively tall road signs and high crosswalk buttons were found to hamper orientation of few MobAD users in a university campus, as most of those sit lower than ambulatory pedestrians. Despite the variations in study populations and spatial contexts, the above findings suggested that construction of public pathway infrastructure without considering a wide breadth of functional capabilities might adversely impact a range of MobAD.

MobAD users often find themselves psychosocially dysfunctional due to insecure pathway conditions. Lid and Solvang [48] conducted a study to unveil the lived experiences of vulnerable people navigating in urban environments. The study found that unsafe pathways – primarily due to uneven or narrow sidewalk surfaces – diminished MobAD users' willingness to navigate outdoors as well as damaged their self-esteem. In a different setting, Stafford et al. [61] explained that children MobAD users were reluctant to navigate or socialise on sidewalks due to physical barriers – predominantly absent curb ramps, rough surfaces, and narrow sidewalks – because of personal safety risks. In the same vein, Corazon et al [62] reported that safety fears due to excessively sloped or uneven pathways deterred MobAD users from visiting natural spaces, such as parks. Results from the above studies suggested that inaccessible pathways can coerce MobAD users into isolating from urban life and society as well as impose psychological damage on vulnerable individuals.

3.2.2. Transport facilities

The physical gap between platforms/stops and vehicle floors was deemed to be a significant burden for MobAD users. Boarding ramps were also found to jeopardise users' safety and autonomy. Inaccessible transport infrastructure hampered autonomy and personal development of MobAD users. Figure 3 illustrates the impact of transport physical infrastructure on different facets of QoL of MobAD users.

[Figure 3 – please see appendix]

3.2.2.1. Insurmountable physical gaps and precarious boarding ramps. Existing physical gaps between platforms/stops and vehicle floors were non-negotiable for MobAD users. Two experimental studies undertaken in different research contexts – i.e., in Netherlands and France, respectively – agreed that gaps of more than a certain threshold (i.e., 50mm X 50mm, measured in width x height) could inhibit users from boarding/alighting transport vehicles [63,64]. In other words, these types of gaps would obstruct both horizontal and vertical access to transport vehicles. However, both experiments were conducted in mock-up environments and ruled out significant actual parameters – such as the flow of fellow travellers – which could influence MobAD access in real-life situations. Nevertheless, results from both studies are valuable indicators of acceptability thresholds for transport infrastructure regarding independent navigation of MobAD users. It is probable that most transport systems are not in position to align with the aforementioned standards due to inconsistent physical infrastructure. For example, uneven terrain at bus drop-off points could expand the vertical gap between bus floor and ground surfaces, thus compounding difficulty of MobAD users when boarding/alighting buses [65].

A temporary solution for bridging physical gaps in transport operations is boarding ramps, which are extensively used in train stations and bus stops. However, boarding ramps were frequently found to exceed the allowable slope thresholds [65,66]. In many cases, this can be attributed to careless ramp deployment combined with operator practices – e.g., not fully kneeling buses – or physical constraints, for instance due to limited available space between buses and ground-fixed bus shelters. Excessive ramp slopes could result in injurious accidents (e.g., concussions and femur fractures) and physical strain for MobAD users when boarding or alighting transport vehicles [67,68]. Specifically, it was observed that as the gradient of the ramp incline increased, upper limb demand (i.e., musculoskeletal fatigue) and injury risk for wheelchair users also increased [69]. Another research cohort disputed the capacity of boarding ramps to securely accommodate MobAD users even within acceptable limits by accessibility regulations. D'Souza et al. [70] found that ramp slopes within permissible limits (i.e., 1:6 gradient, as per the Americans with Disabilities Act Guidelines, 2010) caused physical discomfort to wheelchair and scooter users. This agreed with Lenker et al. [66] who argued that ramp slopes within the previous limits were likely to obstruct unassisted boarding and alighting for wheelchair users. Both study samples did not include users of ambulation aids, for instance canes and crutches, who comprise a large population of MobAD users. Although further research is yet needed with this population, findings from all above studies indicate that using boarding ramps can be a taxing task for the majority of MobAD users.

3.2.2.2. Inaccessible transport infrastructure – an obstacle for autonomy & personal development. Apart from jeopardising MobAD users' health and safety, inaccessible transport infrastructure can affect their independence and development. Confined and crowded places, for instance train platforms, had significant impact on MobAD users' autonomy in terms of using public transport [59]. Another study showed that many MobAD users experienced a "loss of autonomy" and feelings of exasperation due to reliance on presence of transport staff in order to use boarding ramps [71]. Those findings possibly infer that inaccessible infrastructure dissuaded MobAD users from using public transport for performing every-day tasks. According to Aldersey et al. [46], this could heavily impact MobAD users' participation in community activities, such as shopping, as well as employment opportunities. Likewise, Chiwandire and Vincent [72] indicated that transport deficiencies – mainly due to the physical gap between bus stops and bus floors – could inhibit many young MobAD users from accessing university campuses. Evidence generated by these studies highlights that inaccessible transport could curtail equal opportunities among members of society, especially in employment or education.

3.2.3. Building approach

Building approach areas were found to include problematic elements that imposed multifaceted issues on MobAD users. Built ramps and entrance characteristics – such as doors and doorways – were most frequently discussed by the collected content. Figure 4 outlines the impact of building approach elements on different QoL aspects of MobAD users. [Figure 4 – please see appendix]

3.2.3.1. *Built ramps – a cause of physical pain and discomfort.* Ramps are internationally used for providing access to MobAD users to approach building entrances; nevertheless, their usability and safety have been questioned by many researchers. Results from a cross-sectional study concluded that propulsion on inclined ramp surfaces was the primary cause of shoulder pain for users of manual wheelchairs [73]. The same study underlined that chronic shoulder pain could cause upper-extremity activity limitations [73]. These findings denote that prolonged ramp propulsion can probably affect lifting or pushing capabilities of MobAD users and eventually lead to functional performance deficits. Other researchers studied wheelchair users' physiological strain and vertical navigation challenges in relation to ramp characteristics – i.e., running slope, cross-slope, running length, and height – and proposed their own guidelines for designing ramp slopes accordingly [74,75]. While both studies identified that physical strain increased as ramp slope increased even within permissible limits (i.e., 1:12 gradient, as per the Americans with Disabilities Act Guidelines, 2010), accessibility designers and architects should consider that those studies only referred to wheelchair users. It would be useful for design practitioners to examine the whole range of MobAD users – including, for instance, scooter and cane users – before generalising these guidelines. Even so, improperly built ramps would be difficult to amend, given their intrinsic structural rigidity. The above findings might propel the discussion that a more flexible means of providing access to buildings should be sought.

3.2.3.2. Ill-suited building entrances as impediments to healthy habits and social participation. Entrance features – such as doors and doorways – were accredited with inflicting manifold issues on MobAD users as per the reviewed literature. Narrow doorways and limited pull spaces were deemed to most deter MobAD users from entering commercial stores by a number of studies [45,46,49,58]. This may have a grim economic impact on local businesses due to lack of accessible entryways provision to a great number of potential customers. Door features and materials also impacted MobAD users. Abu Tariah et al. [76] suggested that doors with high handles inhibited MobAD users from accessing mosques. This situation forced MobAD users to pray in isolation in their homes, thus preventing them from participating in an important part of their faith [76]. In addition, Leong and Higgins [77] reported that heavy, manually-operated doors were the biggest challenge for MobAD users with respect to accessing public libraries. It was therefore probable that wheelchair users had less access to information than other members of society [77]. The above findings suggest that problematic entrance characteristics can be critical factors for the exclusion of MobAD users from social activities and commercial services. This might impel design practitioners to embrace responsive techniques – for instance, automatically-actuated doors and door handles – or comply with relevant accessibility guidelines (such as in ADAAG 2010) so as to create entrances that could adapt to the needs of MobAD users.

An emerging topic is the possible association between entrance accessibility and healthy habits of MobAD users. Problematic entrances of groceries and fitness centres were deemed to deprive MobAD users of access to healthy foods and physical activity, respectively. Mojtahedi et al. [78] examined MobAD-accessibility of grocery stores in an urban area and found that more than half of those had inaccessible entrances – mainly due to heavy, manual doors with limited pull space. The study suggested that entrance inaccessibility was a major barrier for MobAD users in accessing healthy foods (e.g., lean meat and fruits); a condition that could gradually lead to malnutrition [78]. Elsewhere, Dolbow and Figoni [79] explored the level of MobAD-accessibility of fitness centres in a metropolitan area. They found that half of the facilities required the ability to grasp a door handle and manually open heavy entrance doors. This could impede access to fitness centres for MobAD users and decrease their levels of physical activity consequently [79]. While findings from both studies cannot necessarily be generalised to other geographic areas, they can serve as valuable reference points for future studies on possible effects of inaccessible entrances on healthy habits of MobAD users.

3.2.4. Indoor facilities

Indoor facilities of buildings of public interest included a great number of inaccessible physical elements. Confined spaces – i.e., narrow corridors and restrooms – were often mentioned as a burden for MobAD users' independence. Moreover, retail interior environments – such as shopping malls, commercial stores, and groceries – encompassed safety threats and functioning barriers for MobAD users. Figures 5 and 6 summarise the impact of building indoor facilities on different facets of MobAD users' lives.

[Figures 5 and 6 – please see appendix]

3.2.4.1. Confined spaces obstructing independent living. Narrow corridors were found to impede independent navigation of MobAD users. Koontz et al. [80] argued that the majority of MobAD users could not successfully complete 90º and 180º turns through corridors of legally permissible width (i.e., with minimum openings of 91.5cm and 152.5 cm respectively, as per the Americans with Disabilities Act Guidelines, 2010). The study omitted the synergistic effects of surface friction, which can negatively influence users' manoeuvrability over rough surfaces, such as carpet floorings [55]. However, the special weight of this study derives from its methodological robustness, as researchers tested a large and diverse sample (i.e., 213 users of manual and power wheelchairs as well as scooters) to reach the previous conclusions. Later findings reinforced the negative impact of narrow corridors on MobAD users' manoeuvrability, as Dutta et al. [81] suggested that scooter users could not complete 90º and 180º turns through corridors that complied both with American and Canadian accessibility guidelines. In addition to manoeuvrability impediments, the study found that narrow corridors could diminish reach capability of scooter users. That is, no scooter users would be able to perform a side approach to a counter within a confined space allowed by existing standards [81]. This was also true for users of power wheelchairs, as indicated by Holliday et al. [82]. Their results showed that users might enter a space, however they had limited reach capability and were only able to exit the space, without collisions, by driving in reverse [82]. Consequently, overall findings from the previous studies imply that a revision of existing accessibility guidelines is required so that MobAD users can successfully negotiate corridor-type conditions in public buildings, such as dead-end halls, cordoned-off ques, or approaching sinks in restrooms.

Physical characteristics of restrooms included substantial barriers for MobAD users. Narrow public restrooms impeded the manoeuvrability of MobAD users, as a number of international studies indicated [49,72,83,84]. Absence or ineffective placement (i.e., higher or lower than MobAD users' achievable height) of handhelds/grab-bars could negatively impact the ability of users to transfer themselves from their devices to toilet seats [85,86]. Outside transferability, restroom inaccessibility might inflict indirect health problems to MobAD users. One study revealed that a few MobAD users experienced relevant health issues – for instance urinary tract infections – as a consequence of inability to toilet due to inappropriate restroom design [46]. While these results cannot be generalised due to their regional character, they signify a new field for further investigation since restrooms are closely connected with personal hygiene.

3.2.4.2. Barriers for independent functioning and safety threats lurking in retail interior environments. Problematic features of retail environments were a common topic among the literature. Existence of stairs was an insurmountable barrier for wheelchair and scooter users in various commercial environments, which completely hindered their vertical navigation among building floors [43,44]. For Tripathi et al. [87], stairs and escalators were predominant causes of injurious incidents – including head-related injuries – in shopping malls. This was the only study among the reviewed content, which examined possible impacts of problematic elements of public spaces on users of strollers and prams – i.e., infants and young children. Few studies reported that store aisles and service surfaces (e.g., counters and shelves) were amongst the least accessible elements in retail interior environments, as they were frequently found not to comply with statutory standards [58,88–90]. Narrow aisles and inaccessible elements would probably have dramatic effects on MobAD users' independent manoeuvrability and reach capability respectively; however limited evidence was found within the reviewed content. Other researchers indicated that narrow aisles significantly hampered MobAD users' manoeuvrability within convenience stores [89,91]. Moreover, improper placement of service surfaces (i.e., exceedingly low, high or deep elements) diminished the users' ability to reach items from overhead shelves or pay at checkout counters [89,91]. Due to the regional focus of those studies, more empirical evidence is needed to corroborate the previous outcomes in an international level.

4. Discussion

This review identifies the most significant physical barriers in public spaces and explores the impact of inaccessible spaces on QoL aspects of MobAD users. Findings indicate a substantial number of inaccessible elements for MobAD users in public spaces. *Pathway characteristics, boarding ramps, entrance features, confined spaces*, and *service surfaces* are deemed to be the least accessible elements. These barriers have multifaceted effects on MobAD users' QoL with aspects of physical health and safety, mobility, and use of public transport being most affected.

In our findings, design characteristics of existing physical elements of public spaces are often found not to comply with accessibility guidelines. *Height differences, limited widths*, and *excessive slope gradients* are common factors for the observed incongruence. Those outcomes agree with international studies, which have found that the actual design of several physical elements does not harmonise with accessibility standards [92–94]. A possible explanation of this might be that a substantial portion of public spaces had been constructed before accessibility standards were introduced. Other scholars have attributed this incongruence to a common perception among spatial designers that the application of accessibility laws can be too restrictive in terms of aesthetics and forms, diminish spatial usability, or increase construction costs [95,96]. Failure to comply with accessibility regulations has resulted in much of the urban environment having been built in a way that does not correspond to MobAD users' functional capabilities.

In an international context, accessibility regulations safeguard that spaces and buildings of public interest are accessible to all individuals, regardless of their functional statuses [40,97]. Nevertheless, our review indicates that several physical elements within allowable accessibility standards impede independent functioning of a large percentage of MobAD users. Specifically, confined spaces and excessively high service surfaces are frequently linked to setbacks in *manoeuvrability, transferability, toileting*, and *reach capability* of MobAD users. An underlying reason for this can possibly emerge from advisory frameworks – i.e., research that underpins accessibility standards development – shortcomings. Field experts have argued that advisory frameworks often ignore variation in body sizes, functioning capacity, and MobAD technologies [98,99]. As a result, much of the built environment has been structured as though individuals have identical needs and functioning capabilities [100,101]. This can prove to be detrimental for MobAD users at the lower end of the functioning spectrum.

A direct consequence of the limitations in functioning is reflected in the degree of MobAD users' participation in society and everyday activities. We have found that several aspects of social participation for MobAD users are affected due to inaccessible spaces, predominantly the *use of public transport*. The review results indicate that inaccessible transport infrastructure could prompt a *deficit in education and employment opportunities* for MobAD users when compared to non-disabled individuals. These findings confirm the association between transport accessibility and social inequality [102,103]. Furthermore, inaccessibility of entrances of public buildings is found to be a critical factor for the exclusion of MobAD users from *social activities* and *commercial services*. These outcomes are in agreement with previous research that associated lack of physical accessibility to socioeconomic inequalities internationally [104,105]. Significantly, societal exclusion can exacerbate stigma amongst MobAD users, thus making them lose their sense of belonging [106]. At the same time, employment and education inequalities for MobAD users are most likely to engender macro-economic losses for societies [107].

Our review suggests that MobAD users bear a greater health impact compared to the general population. We foreground some latent health issues – such as *physical inactivity, malnutrition*, and *chronic shoulder pain* – as indirect consequences of accessibility barriers in public spaces. Evidence from other studies has shown low healthcare utilisation amongst MobAD users due to inaccessible environments in healthcare facilities, as in prenatal care [108] and cancer services [109]. We can thereby presume that access barriers in the built environment propel health inequalities for MobAD users. According to WHO [110], such inequalities can lead to premature mortality and increased healthcare costs.

Taken together, results of this review really underline assertions of various disability scholars and activists who have contended that the presence of physical barriers increases exclusion and inequalities [111,112]. This is particularly true for public spaces that abound with single-function, rigid elements – for instance, confined spaces, concrete steps, stairs, and manual doors. Previous research has also shown similar types of *inflexible elements* constrain human activities by failing to accommodate people of diverse needs and capabilities [113,114]. Another example of spatial inflexibility derives from the ineffectiveness of most physical elements in accommodating more than one MobAD users at a time – e.g., elevators. While fully functioning individuals are seldom affected by inflexibility, such elements are found to be insurmountable access barriers for MobAD users, as our results indicate. This resonates Imrie's [115] theory of "*design apartheid",* which blames inept design of physical environments for acting as a "disabling" factor that discriminates against users of spaces by impeding their access [115]. It is therefore possible that inflexible elements are *disabling* *features* of the built environment, thus perpetuating social and spatial injustice in public spaces.

5. Strengths & limitations

This review provides a holistic assessment of the level of physical accessibility of public spaces in the urban environment. That is, we examined multiple components of the built environment in relation to everyday activities of MobAD users – such as navigating outdoors or using the public transport. This allowed us to discover many possible linkages between problematic physical elements and life aspects of MobAD users.

The current findings provide additional evidence on the role of inflexible elements of public spaces as disabling features, which can totally exclude MobAD users or compel them to conform to unsafe or inconvenient spatial situations. These results can be particularly meaningful to policymakers and built environments professionals, as they are obvious indicators that more effective approaches should be sought to ensure that public spaces can support human performance for all.

To the best of our knowledge, this review is the first to report possible effects of physical inaccessibility on health and safety aspects of MobAD users. Our findings suggested that poorly designed public spaces can be regarded as a double health burden, as they can threaten the physiological state of MobAD users as well as deter their access to healthy lifestyles. However, more research is required to corroborate these findings, which would also benefit policymakers.

Previous research did not manage to establish the impact of physical barriers on separate mobility aspects of MobAD users. Contrastingly, the current review includes several experimental or observational studies of commendable methodological quality, which determined the impact of manifold physical forms on independent mobility. This allows us to identify in what ways spatial factors – especially narrow corridors and wide/high gap between transport vehicles and platforms/stops – affect different mobility activities (i.e., horizontal and vertical navigation, and manoeuvrability).

Another strength of this review is that it extends the scope of research on urban accessibility by exploring possible effects of physical barriers on functioning aspects of MobAD users beyond mobility. We particularly report associations between physical inaccessibility and setbacks in transferability, reach capabilities, and toileting.

Regarding the limitations of this review, the topic of this review – physical inaccessibility of public spaces and QoL aspects – is very broad, thus making the search for articles challenging. Because of this breadth of the subject, there is a possibility that some relevant studies were not found, which might limit the scope of our findings. Although we explored multiple databases and consulted a research librarian to develop a comprehensive search strategy, we did not register the used strategy in a protocol registry. A further limitation of this study is the exclusive focus on MobAD users. Notwithstanding the previous limitations, we believe that the methodology and structure of this review is reproducible for future research.

6. Gaps in research

The vast majority of the reviewed studies originated in high-income countries, which translates into limited knowledge on physical accessibility and QoL of MobAD users in the rest of the world.

Most findings concerned users of either manual or electric-powered wheelchairs, thus leaving users of crutches and canes, strollers/pushchairs, rollators, and mobility scooters underrepresented in research. This can be corroborated by low levels of sample representativeness, which emerged as a limitation in many studies.

A noteworthy remark derives from the fact that potentially inaccessible public spaces were overlooked across the reviewed literature. This might have resulted in an omission of a series of physical elements or design features, which could be potentially impacting various QoL aspects of MobAD users. For instance, no studies were found to investigate MobAD-accessibility of theatre halls or stadia. Seating arrangements in these types of public spaces are likely to posit difficulties to MobAD users regarding vision range capacity or body fit. This is an important issue for future research. Also, the reported absence of age-specific or culture-specific places – such as school environments or galleries – might have prevented researchers from generating knowledge regarding MobAD users of certain age groups or socio-economic statuses.

Therefore, there is a scarcity of research in the field of MobAD-accessibility of public spaces in terms of social and spatial representation. This indicates that more empirical studies are needed to explore a wider range of public spaces and physical elements as well as examine impact of physical barriers on diverse populations of MobAD users.

7. Recommendations for research & practice

In response to the negative phenomenon of physical inaccessibility and subsequent pressure on MobAD users, we propose a series of human-centred approaches.

Firstly, many of the reviewed studies implied that spatial designers and policymakers often ignore the "MobAD users' voices" when planning public spaces. As such, public spaces failed to meet MobAD users' expectations despite conformity to accessibility guidelines or designers' intentions to facilitate MobAD users. Local governments should encourage and welcome MobAD participation in the planning processes of public open spaces and buildings. *Participatory planning* proffers an efficient way to optimise usability of the built environment [134]. This can be a democratic way to solicit MobAD users' preferences and identify common barriers pro-actively as early as in planning stages as well as minimise the risk of subsequent physical modifications. Moreover, participatory planning can reconcile the chasm that often occurs among urban and transport planners, architectural/urban designers, designers of MobAD, and MobAD users. Participatory meetings can lever the creation of multidisciplinary design teams to come together and address such shortcomings together with actual MobAD users.

Secondly, there is a clear need that research underpinning accessibility standards should explore a wider range of user characteristics. *Universal design* is an approach that accommodates and empowers a diverse population by improving health and wellbeing, human functioning, and social participation [116]. This approach harnesses empirical knowledge from anthropometrics and biomechanics to estimate spatial requirements for a wide spectrum of individuals by considering diverse functional capabilities [8,21,116]. Accessibility research should adopt a "universal design" outlook so that international guidelines could become more conscious of different body dimensions, health conditions and types of assistive devices.

Thirdly, it was found that inflexible elements in the built environment, such as steps or manual doors, heavily obstructed access of MobAD users. Contrary to conventional design approaches, which engender inflexible elements, *adaptive architecture* refers to the ability of elements of the built environment to adapt according to the needs or desires of their occupants [117]. Unlike traditional rigid structures, adaptive ones comprise dynamic configurations that can continuously change in form and function [118]. Adaptation can potentially embody the philosophy of universal design; in certain cases, physically transformable elements have facilitated a diverse population through adapting to a wide range of functional capabilities. An exemplar of this approach is the adaptable platform of Stockholm Opera that functions as both an accessible lift and a flight of steps/stairs to accommodate MobAD users and non-disabled individuals (figure 7). Researchers and practitioners should further examine the role of adaptation as an assistive technique, which can transform static entities into flexible elements, to maximise independent functioning of MobAD users in public spaces.

[Figure 7 – please see appendix]

8. Conclusion

It becomes evident that current design practices deliver public spaces of substandard quality insofar as disability access is concerned. This is due to (a) their disregard for functional capabilities of a diverse population, and (b) the innate inflexibility of physical elements. These two factors have systematically rendered public spaces inadequate to cater for the needs of those who do not fit the criterion of fully-functional capabilities – including MobAD users. Hence, design of the built environment becomes an actor of disablement and has tremendous impact on MobAD users' lives. We believe that universal design and adaptive architecture are two approaches that can decisively improve physical accessibility of public spaces and thereby enhance QoL of MobAD users in cities.

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Appendix

Searched terms lists			
MobAD users	**QoL aspects**	**Physical elements**	
"mobility device*"	access*	pathway*	built
wheelchair*	"quality of life"	footpath*	architectur*
scooter*	health	sidewalk*	environmental
"walking frame*"	well-being	pavement*	"public space*"
"walking stick*"	safety	"street furniture"	"open space*"
rollator*	"daily activities"	"ground surface*"	"public building*"
"walking cane*"	"daily tasks"	"walking surface*"	"green space*"
crutches	comfort	"curb ramp*"	square*
pushchair*	fatigue	"curb cut*"	plaza*
stroller*	pain	entrance*	park*
"mobility impair*"	psychological	door*	water*
"mobility disab*"	psychosocial	transport*	librar*
"wheeled device*"	"self-esteem"	"bus (transport* or platform*)"	school*
"mobility assistive device*"	emotional	"train (transport* or platform*)"	universit*
	"bodily image"	"tram (transport* or platform*)"	cinema*
	independence	parking	shop*
	transport	"emergency exit*"	retail
	transfer	"evacuation point*"	museum*
	maneuverability	"ground surface*"	store*
	mobility	"floor surface*"	restaurant*
	"reach range"	corridor*	market*
	"reach *abilit*"	aisle*	church*
	grip	ramp*	mosque*
	force	"platform lift*"	café*

	"vision range"	elevator*	playground*
	participation	stair*	stadi*
	recreation*	step*	theatre*/theater*
	leisure	handrail*	fitness
	spirituality	"dining surface*"	urban
	religion	"work surface*"	cit*
	education*	"service surface*"	
	"social relations*"	counter*	
		shelf/shelves	

Explanations: Double quotation marks were used to search for a loose phrase. An asterisk was used to retrieve variable endings of a root word.

Table 1: Construction of the search query used for retrieving relevant literature.

Classes of information	Codes
	Authors
	Year of publication
	Country
	Methodological approach
	○ Study design (e.g., descriptive, explanatory)
Article characteristics	○ Data collection techniques (e.g., survey, lab trial) & Sample size
	○ Data analysis techniques (e.g., quantitative, qualitative)
	Quality of evidence
	○ Study limitations (e.g., existence of confounders)
	○ MMAT rating (e.g., 80% criteria met)
	Purpose
	○ Thematic focus (e.g., physical accessibility, impact on QoL)
	○ Types of MobAD examined (e.g., manual wheelchairs, canes)
	Main findings
Objective-related insights	○ Types of public spaces examined (e.g., street infrastructure)
	○ Types of physical elements examined (e.g., curb ramps, pathways)
	○ Impacted QoL domains (e.g., pain and discomfort, body fit)

Table 2: Coding scheme used in this review.

Publication details	*Purpose & type of MobAD examined*	*Study design* *Data analysis & collection methods; Sample size* *MMAT rating; Limitations*	*Key findings*
Abu Tariah et al. (2018); Saudi Arabia	To explore ***wheelchair*** accessibility of mosques in Riyadh from the perspective of users.	Descriptive QUANT., Social survey; N=48 80%; sample representativeness	Mosques were inaccessible for wheelchair users. This impacted their spiritual condition.
Aldersey et al. (2018); Bangladesh	To explore barriers and facilitators for ***wheelchair*** users.	Exploratory QUAL., Interviews; N=20 80%; inefficient data collection methods	Participants mentioned a few barriers in public spaces (pathways, ramps, bus stops) that affected them diversely.
Alm et al. (2008); Sweden	To document the prevalence of shoulder pain, interference in activities of ***manual wheelchair*** users.	Descriptive QUANT., Social survey; N=88 60%; sampling strategy, sample representativeness	The highest median intensity of shoulder pain was reported for pushing the wheelchair up ramps or inclines outdoors.
Bennett et al. (2009); Canada	To determine how much curb ramps in an urban area met a set of accessibility guidelines.	Descriptive QUANT., Spatial survey; N=79 60%; sample representativeness, sampling strategy	Only a small proportion of the studied curb ramps met all the accessibility guidelines. This may impact users' navigation.
Bentzen et al. (2020); USA	To explore effects of tactile walking indicators on users of **wheelchairs, rollators, canes, and crutches**.	Descriptive MIXED, Observation & Social survey; N=38 100%	Crossing either orientation of tactile indicators caused some increase in effort and instability for more than half of participants.

Bromley et al. (2007); United Kingdom	To explore the experiences of ***wheelchair*** shoppers in city centres.	Explanatory MIXED, Social survey & interviews; N=120 80%; sample representativeness	Aisles, shelves, counters, and sidewalks made shopping a frightful experience for wheelchair users.
Carlsson & Lundalv (2019); Sweden	To extract and analyse national ***power wheelchair***-related accident and injury data.	Descriptive QUANT., Official records analysis; N=301 80%; sampling strategy limitations	The reason for many of the single accidents and injuries was a difference in ground level (34%, typically a curb).
Chen et al. (2011); Taiwan	To report ***wheelchair***-related accidents characteristics.	Descriptive QUANT., Interviews; N=95 60%; sample representativeness, confounders	Accidents frequently were caused by narrow pathway passages and uneven surfaces.
Chiwandire & Vincent (2017); South Africa	To describe and assess accessibility measures in South African universities.	Exploratory QUAL., Interviews; N=13 80%; inadequate data collection	Challenges with promoting higher education accessibility for wheelchair users include badly designed toilets, libraries, and transport facilities.
Cooper et al. (2012); USA	To identify and evaluate cross-slope surface characteristics that impact ***manual wheelchair*** mobility.	Descriptive QUANT., Social survey; N=107 80%; survey measurements	Severe cross-slope angles could make it challenging for manual wheelchair users to safely and independently traverse sidewalks.
Corazon et al. (2019); Denmark	To explore the experiences of users of ***wheelchair, scooters, canes, and crutches*** when using green spaces.	Exploratory QUAL., Interviews; N=25 100%	Lack of access - due to uneven surfaces, slopes, inadequate ramps, and poor parking spaces - led to feelings of exclusion and outsideness.

Daamen et al. (2008); Netherlands	To assess the gap between public transport vehicles and platforms as a barrier for ***wheelchairs, rollators, scooters, and canes***.	Descriptive QUANT., Observation; N=165 100%	The 10 cm X 10 cm gap constituted a serious problem for more than half of the participants. Access for nearly all requires a gap size no larger than 5 cm X 2 cm.
Dolbow & Figoni (2016); USA	To determine for fitness centres the level of compliance with ADA.	Descriptive QUANT., Spatial survey; N=10 60%; sample representativeness, inadequate analysis	All surveyed facilities were found to be partially compliant, with none of the facilities being 100% compliant. Service surfaces, confined spaces, and doors were least compliant.
Dutta et al. (2011); Canada	To determine space needed for powered mobility ***scooters*** to manoeuvre indoors.	Explanatory QUANT., Lab trials; N=1 80%; sample representativeness	None of the scooters tested could complete all manoeuvres within the confined space limits allowed by existing standards.
Duvall et al. (2013); USA	To develop a guideline for public pathways and sidewalks for users of ***wheelchairs***.	Explanatory MIXED, Observation & survey; N=61 100%	Surfaces with wide and frequent cracks subjected wheelchair users to harmful whole-body vibrations and were uncomfortable for users of wheelchairs.
Evcil (2018); Turkey	To evaluate ***wheelchair*** users' participation in recreation activities in a heritage site.	Descriptive QUANT., Social survey; N=125 80%; weak sampling strategy	There are significant physical obstacles that hamper access to leisure activities, such as pathway characteristics, absence of ramps, existence of stairs, and problematic entrances.
Evcil (2009); Turkey	To determine the compliance of public buildings to ***wheelchair*** accessibility guidelines.	Descriptive QUANT., Spatial survey; N=26 60%; sample representativeness, sampling strategy	Ramps, doors, parking spaces and sidewalks were the found to be the most problematic elements.

Frost & Bertocci (2010); USA	To characterise ***wheelchair & scooter*** adverse incidents on transit vehicles.	Descriptive QUANT., Official records analysis; N=115 80%; non-response bias	Wheeled mobility devices users have a greater chance of incurring injury during ingress/egress on boarding ramps.
Frost et al. (2020); USA	To solicit feedback on boarding ramp related incidents and difficulties from **wheelchair & scooter** users.	Descriptive MIXED, Social survey; N=384 80%; non-response bias	Steep ramp slope was the primary contributing factor to most incidents. Users questioned ramps accessibility.
Gamache et al. (2020); Canada	To objectively describe environmental obstacles encountered by **wheelchair, scooter, crutches, and canes** users.	Descriptive MIXED, Spatial survey & Interviews; N1=20, N2=10-15 80%; sampling strategy	Access ramps and washrooms should be considered for improvement.
Grange-Faivre (2016); France	To determine the maximum gap between transport vehicle & platform for ***wheelchairs & canes*** users.	Descriptive QUANT., Observation; N=46 80%; existence of non-accounted confounders	Nearly half the manual wheelchair users failed the gaps of 50 mm × 50 mm and larger.
Henje et al. (2021); Sweden	To identify obstacles and risks for ***power-wheelchair*** users by exploring their behaviour and experiences in traffic environments.	Exploratory QUAL., Interviews; N=15 60%; sampling strategy, sample representativeness	Uneven and non-uniform pathways are major obstacles and causes of accidents for users of powered mobility devices.
Holliday et al. (2005); Canada	To determine ***power wheelchair*** manoeuvrability factors for reach range in confined space.	Exploratory MIXED, Social survey & Lab trials; N1=123, N2=1 60%; sample representativeness, sampling strategy	Power wheelchairs users would not achieve maximum reach capability within the space width allowed by existing standards.

Hurd et al. (2008); USA	To evaluate ***manual wheelchair*** propulsion across level ground conditions.	Explanatory QUANT., Observation; N=14 60%; inappropriate measurements, confounders	Carpet flooring and aggregate concrete were found to be the most physically-demanding for indoor and outdoor use, respectively.
Jang et al. (2019); Canada	To explore everyday experiences of ***scooter*** users as they navigate outdoors.	Exploratory QUAL., Interviews; N=20 80%; data collection methods	Common barrier locations included existence of steps, uneven sidewalk surfaces, and doors.
Khalili et al. (2021); Canada	To evaluate how personal, environmental, and device-related factors impact the perceived autonomy of users of **wheelchairs & scooters**.	Descriptive QUANT., Social survey; N=123 80%; sample representativeness	Manoeuvrability on uneven/rough terrains and at confined spaces vastly impacted autonomy of MobAD users.
Kim et al. (2014); Korea Republic	To understand the effects of ramp slope and height on ***wheelchair*** users' propulsion force.	Explanatory QUANT., Lab trials; N=30 80%; sample representativeness	Accessibility of the ramp decreased as the slope increased, and accessibility difference between slopes increased as the height increased.
Koontz et al. (2020); USA	To identify facilitators and barriers to ***wheelchair*** **& scooters** transfers in the community.	Descriptive QUANT., Social survey; N=112 80%; sample representativeness	Wheeled mobility device users had limited transferability with respect to wrongly-located grab-bars and facility surfaces, confined spaces, and toilets.
Koontz et al. (2010); USA	To determine minimum space required for 4 different types of turns for ***wheelchair & scooters***.	Explanatory QUANT., Lab trials; N=213 80%; sample representativeness	Between 10% and 100% of users would not be able to manoeuvre in spaces that meet current Accessibility Guidelines for Buildings and Facilities specifications.

Labbe et al. (2020); Canada	To explore the experiences of older adult ***powered wheelchair*** users.	Exploratory QUAL., Interviews; N=19 80%; data collection methods	Participants mostly identified issues with entrances and toilets in stores, restaurants and public buildings, and the inadequate conditions of the sidewalks.
Lee et al. (2020); USA	To identify environmental and personal barriers to healthy eating among people with mobility impairments*.	Descriptive MIXED, Social survey; N=112 60%; sample representativeness, sampling strategy	Reaching high or deep store shelves, high tills or check-out surfaces, as well as narrow aisles in convenience stores are access barriers for MobAD users.
Lenker et al. (2016); USA	To assess the usability of ramp slope for ***wheelchairs & canes*** users.	Explanatory MIXED, Lab trials & social survey; N=27 60%; sample representativeness, confounders	The 1:4 slope was too steep. The 1:6 slope was also considered challenging, in terms of safety and fatigue.
Leong & Higgins (2010); Singapore	To explore needs of ***wheelchair***-bound young people regarding library services.	Exploratory QUAL., Interviews; N=11 60%; inadequate data collection & findings representation	The main problem in using libraries was getting through doors. Within the library premises, there were problems relating to stairs, curbs, furniture, shelves, and counters.
Lid & Solvang (2016); Norway	To explore accessibility aspects from a user perspective for ***wheelchairs & crutches.***	Exploratory QUAL., Observation; N=14 100%	MobAD users' access to urban areas was hampered mainly due to sidewalk characteristics, thus hampering their participation in society, and damaging their self-esteem.
Lindemann et al. (2016); Germany	To develop intelligent wheeled ***walkers*** by investigating possible access problems.	Exploratory QUAL., Social survey; N=60 80%; quantitative measurements lacked consistency	Walking downhill and uphill, stairs, and walking outdoors over uneven ground were major problems identified.

Mafatlane et al. (2015); Botswana	To assess accessibility of supermarkets for ***manual wheelchair*** users.	Explanatory MIXED, Spatial survey & interviews; N1=30, N2= 6 80%; sample representativeness	The interior design (aisles, shelves) of the supermarket increased dependency of shoppers who use wheelchairs on activities such as picking items, paying, and reading price tags.
Mojtahedi et al. (2008); USA	To assess the impact of the built environment on access to healthy foods for MobAD users.	Descriptive QUANT., Spatial survey; N=82 80%; sample representativeness	MobAD users are at a disadvantage in staying healthy due to physical obstacles in getting healthy foods (e.g., high shelves & counters, narrow aisles, and inaccessible entrances).
Owusu-Ansah et al. (2019); Ghana	To study the spatial needs of the mobility impaired within the built environment.	Descriptive MIXED, Spatial survey & social survey; N=100 60%; sample representativeness; sampling strategy	Mobility-impaired people navigated through the built environment with great difficulty. Poorly design parking, uneven surfaces and existence of stairs were big challenges.
Pierret et al. (2014); France	To quantify strains during ***manual wheelchair*** travel on cross slopes.	Explanatory QUANT., Lab trials; N=25 100%	An 8% cross-slope is subjectively sensitive and impose physiological costs. A 12% cross-slope is unachievable for some users and should therefore be prohibited.
Prescott et al. (2021); Canada	To explore challenges that users of wheelchairs and scooters face navigating unfamiliar pedestrian environments	Exploratory MIXED, Interviews; N=14 80%; sample representativeness	Uneven and sloped pathway surfaces were key navigational challenges for study participants.
Stafford et al. (2019); Australia	To study neighbourhood experiences of young users of ***wheelchairs & crutches***.	Exploratory QUAL., Interviews; N=12 100%	Children who use mobility aids must compromise safety when navigating on sidewalks due to physical barriers such as narrow space and or poorly designed curb ramps.

Torkia et al. (2015); Canada	To describe ***power wheelchair*** driving challenges from a user perspective.	Exploratory QUAL., Interviews; N=12 80%; data collection methods	Confined spaces, doorways and uneven sidewalks were indicated as the biggest challenges for navigation and manoeuvrability.
Toro et al. (2013); USA	To determine physical elements impact on ***wheelchair*** users' transferability.	Explanatory QUANT., Observation; N=120 80%; confounder affected design and results	Transfer surface heights above and below the device seat height, gaps, and obstacles posed serious transfer-related accessibility problems for MobAD users.
Tripathi et al. (2017); Singapore	To describe ***pram and stroller*** injuries and identify possible risk factors.	Descriptive QUANT., Official reports analysis; N=248 60%; inadequate measurements & nonresponse bias	1 out of 10 patients sustained injuries while the strollers and prams were on escalators and stairs.
Velho (2019); United Kingdom	To explore the barriers faced by ***wheelchair*** users in the transit network.	Exploratory QUAL., Interviews; N=34 80%; inadequate analysis	Crowded and confined spaces impacted autonomy of MobAD users. Reliance on transport staff to deploy ramps aggravated this situation.
Velho et al. (2016); United Kingdom	To research the barriers faced by ***manual wheelchair*** users in public transport.	Explanatory MIXED, Observation & interviews; N1=7, N2=21 60%; sample representativeness, inadequate analysis	As the gradient of the boarding ramp incline increased, upper limb demand and injury risk increased.
Vredenburgh et al. (2009); USA	To evaluate ramp accessibility and perceived effort required for ***wheelchair users***.	Explanatory MIXED, Observation & survey; N1=43, N2=27 100%	For a transit distance up to 6 m (20ft.), a ramp should not exceed a maximum cross slope of 5% or a maximum running slope of 7%

Wretstrand et al. (2010); Sweden	To estimate the incidence of ***wheelchair***-seated passenger injuries related to transit systems.	Descriptive MIXED, Official data analysis & interviews; N1=159, N2=1000 60%; quantitative measurements lacked reliability	Boarding and alighting were deemed to be the most impactful conditions. Most passengers sustained injuries because of their interaction with boarding ramps.

Table 3: Analysis of general characteristics and methodology of the reviewed content

Explanations: "Wheelchairs" refer to both manual and power wheelchairs, unless stated differently. MIXED = Mixed methods, QUAL. = Qualitative, QUANT. = Quantitative. "Evidence quality" level expresses agreement with 5 criteria of MMAT subject to study methodology. * The authors did not specify types of MobAD users surveyed in this study.

Figures

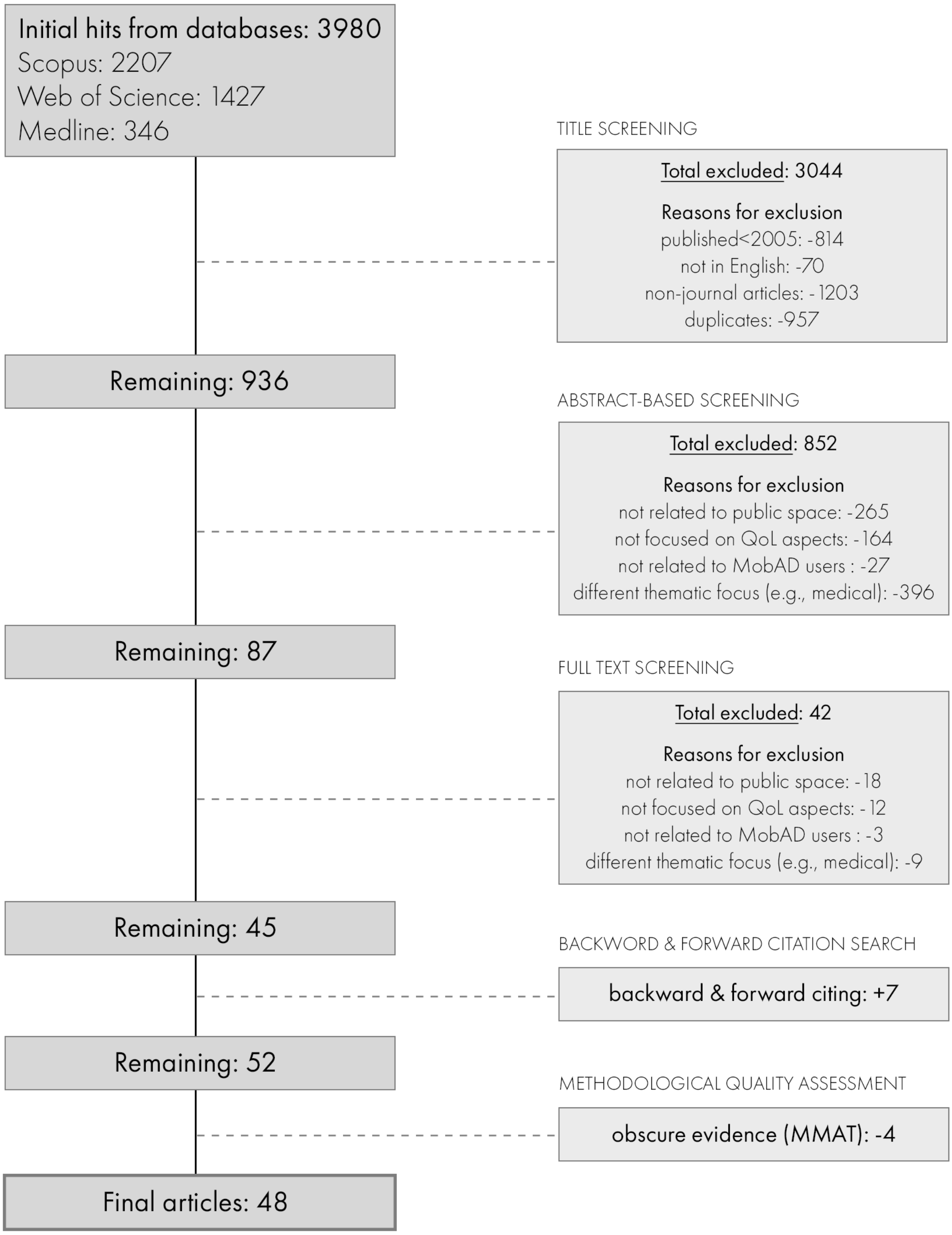

Figure 1: Flowchart of study selection and eligibility criteria

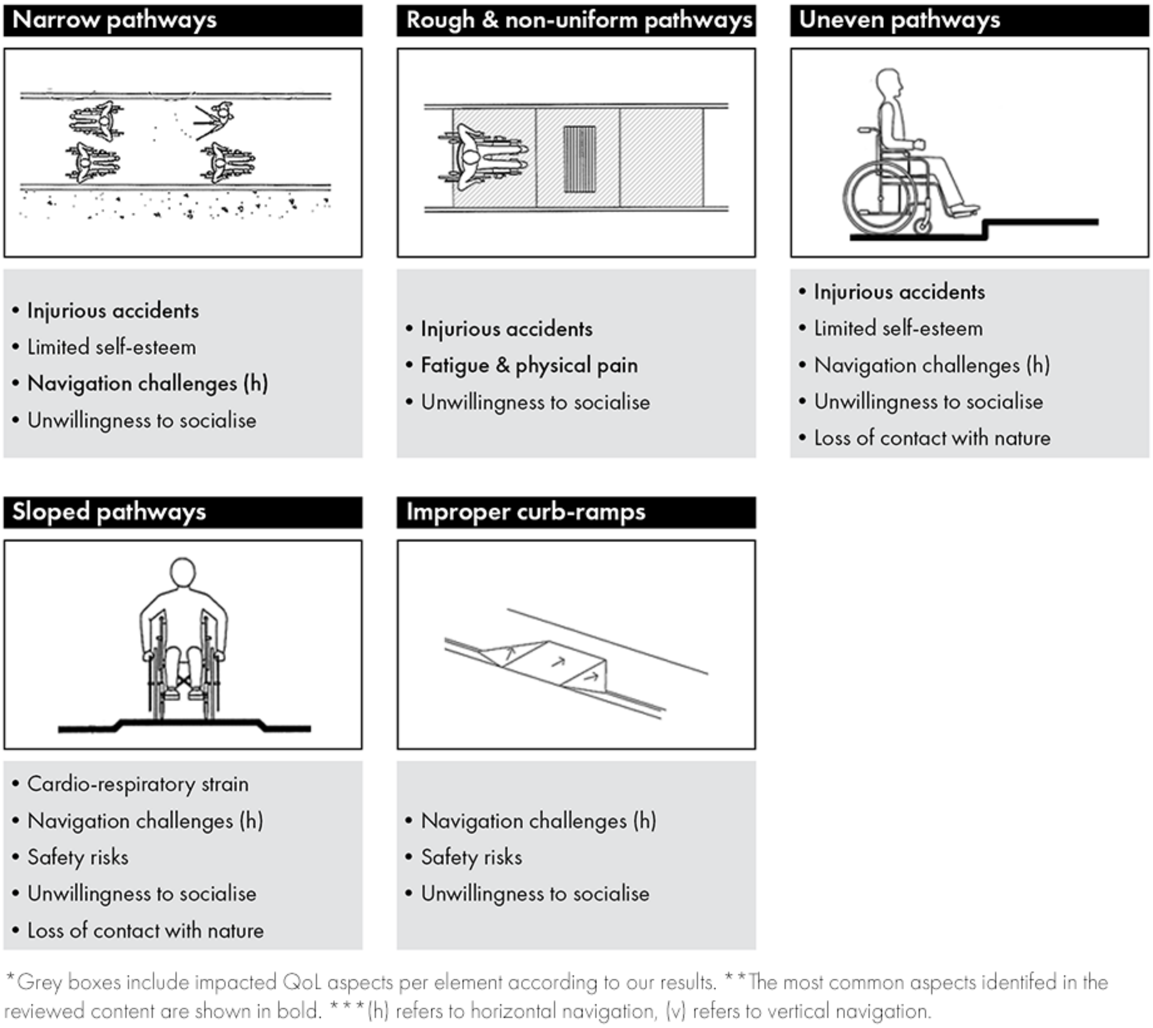

Figure 2: Impact of pathway characteristics on QoL aspects of MobAD users

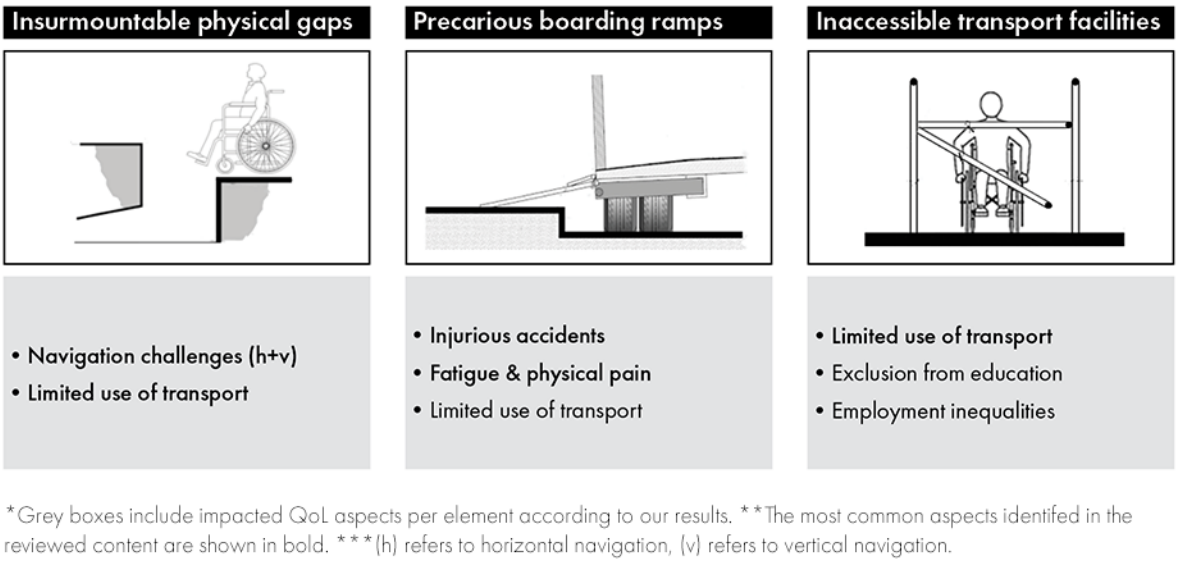

Figure 3: Impact of transport physical infrastructure on QoL aspects of MobAD users

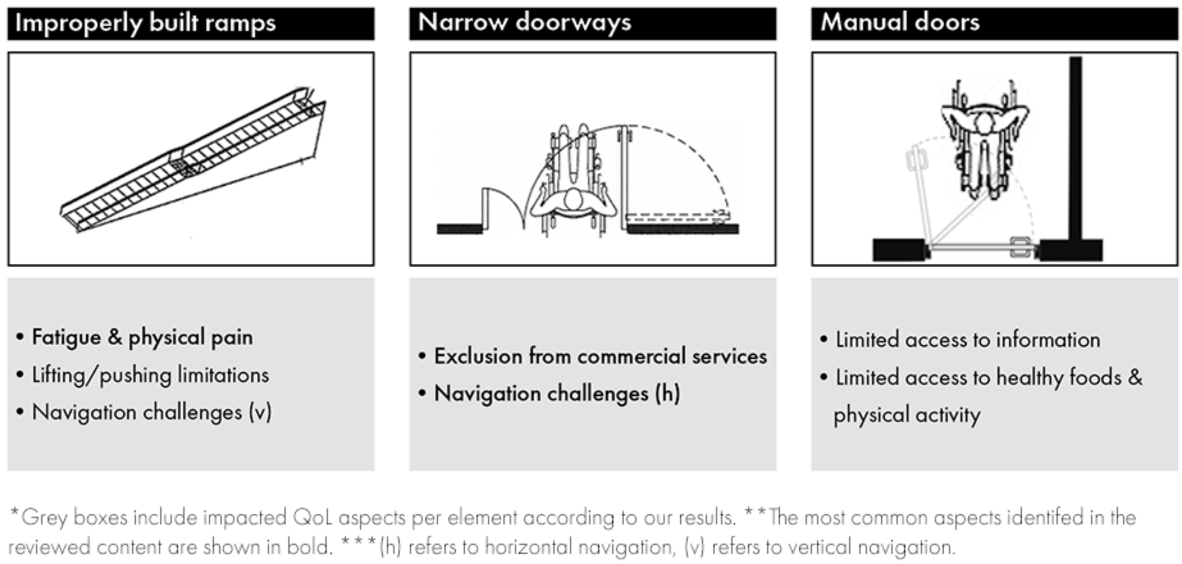

Figure 4: Impact of building approach elements on QoL aspects of MobAD users.

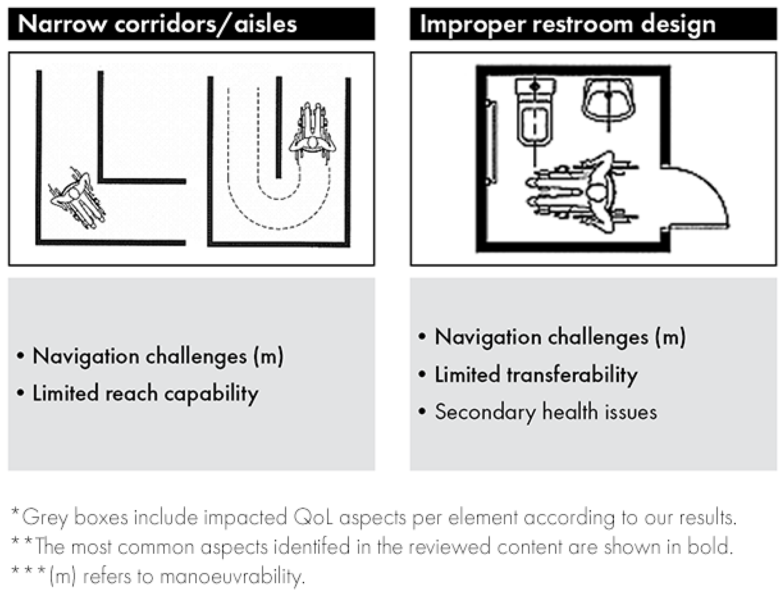

Figure 5: Impact of indoor facilities on QoL aspects of MobAD users - I

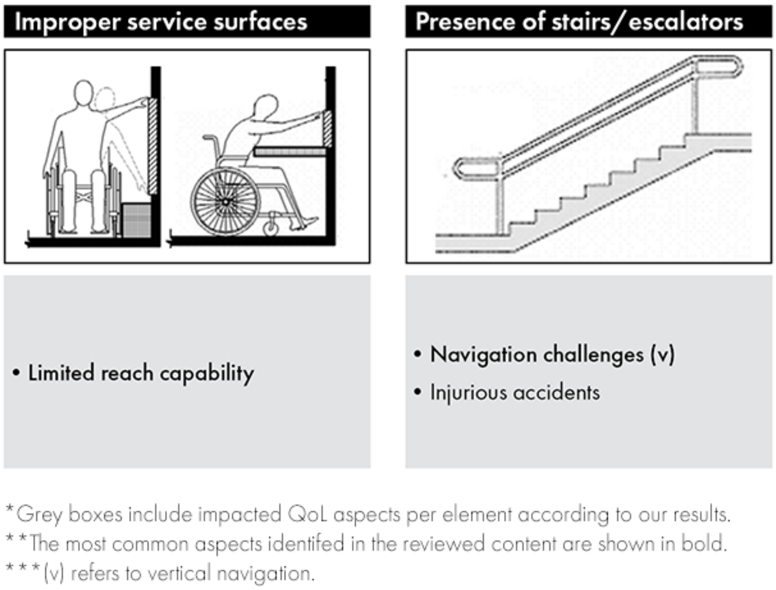

Figure 6: Impact of indoor facilities on QoL aspects of MobAD users – II

Figure 7: Adaptable platform, Stockholm Opera. Image is courtesy of Guldmann Co.

Figure captions

Figure 8: Flowchart of study selection and eligibility criteria

Figure 9: Impact of pathway characteristics on QoL aspects of MobAD users

Figure 10: Impact of transport physical infrastructure on QoL aspects of MobAD users

Figure 11: Impact of building approach elements on QoL aspects of MobAD users.

Figure 12: Impact of indoor facilities on QoL aspects of MobAD users - I

Figure 13: Impact of indoor facilities on QoL aspects of MobAD users – II

Figure 14: Adaptable platform, Stockholm Opera. Image is courtesy of Guldmann Co.