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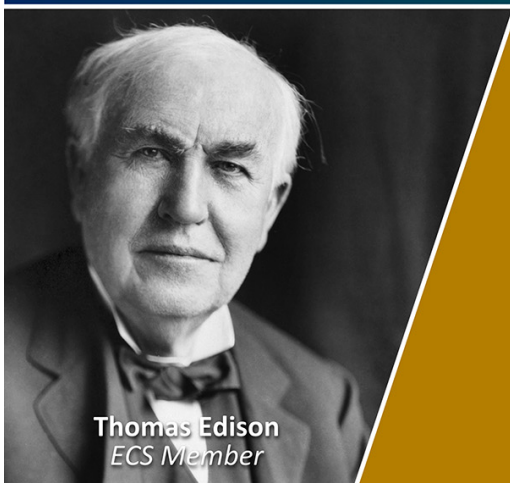
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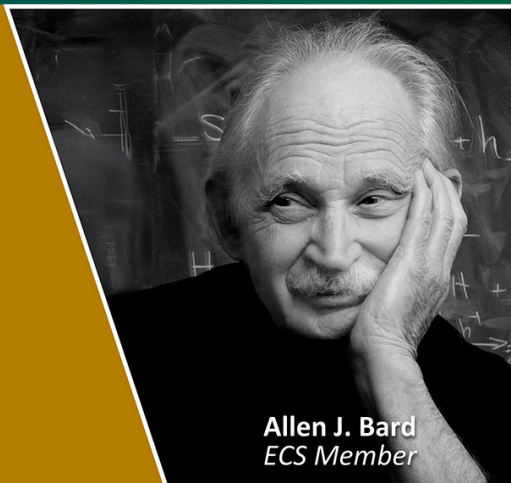
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Improving the built environment for manual wheelchair users: A review

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Abstract. The aim of Universal Design is to make the built environment accessible to all people regardless of disability. This is a laudable aim, but most people are unaware of the many barriers manual wheelchair users actually face when accessing the built environment. The main challenges for manual wheelchair users arise from three areas. Firstly, there are intrinsic limitations arising from the manual wheelchair user's condition and capability. Secondly, there are features such as ramps and cross slopes in the built environment that fail to comply with building codes relating to wheelchair access. Thirdly, there are cosmetic features such as cracked paths, obstructions and poorly placed signage that place an additional burden on manual wheelchair navigation. Each of these three areas is discussed in this article.

The intrinsic limitations of user condition and capability include a wide range of physical impairments and an inherently inefficient manual wheelchair propulsion mechanism. The typical code compliance requirements for wheelchair access in the built environment range from limitations on minimum path widths to maximum permissible ramp slopes. However, even when these features comply with code requirements they may be compromised by temporary obstructions or by poor maintenance so that they become insurmountable challenges to manual wheelchair users. An understanding of these challenges is necessary to improve the built environment so that it is more accessible to manual wheelchair users in the future.

1. Introduction

The principal of Universal Design arose in the late 1900s and aimed to make products and environments usable by everyone, regardless of their disability [1,2]. It requires that the Built Environment (BE) be designed for equitable use by everyone, with simple and intuitive use that requires little physical effort and with appropriate size and space design [3]. It is a difficult goal and meeting the goal varies enormously for different countries, with Norway being the only country aiming to be universally designed by 2025 [4]. About 15% of the world's population lives with some form of disability [5] and the different types of disability (being elderly, visually, physically or mentally impaired) place different, and often conflicting, constraints on universal access to places [6]. For example, at intersections, wheelchair users prefer kerb cuts with gentle slopes and smooth surfaces while the visually impaired prefer a distinct height or surface change that prevents them from inadvertently walking onto a road. The fact that many people suffer from more than one disabling condition makes the problem of universal accessibility even more challenging.



Historically, the severely disabled were placed in institutions that were separate from the general society which meant that the BE developed without considering their accessibility needs. The 1990 Americans with Disabilities Act (ADA) [7] was the first legislation that considered the need to change this status quo [8] and similar legislation followed in other countries. A 2005 United Nations survey of 114 countries showed that 54% had no accessibility standards for outdoor urban environments and streets and that 58% did not allocate any financial resources to accessibility [9]. The 2006 United Nations Convention on the Rights of Persons with Disabilities (UNCRPD) [10] developed a number of articles addressing the rights of the disabled, including those shown in Table 1. Many countries have adopted their own legislation and building codes in an attempt to address the UNCRPD principles. Table 2 shows some exemplars and Vozikis [11] and Jackson [12] provide detailed histories of the gradual integration of the disabled into society alongside improvements to the accessibility of the BE for them. However, the main effort has been to make individual public buildings more accessible while largely ignoring accessibility in local neighbourhoods [12]. It is clear from Table 1 that the intent of the UNCRPD resolutions is much broader than this and that participation in social and community activities is a fundamental right [13]. Despite this the design of the BE remains aimed at able-bodied people in terms of convenience, aesthetics and style [3,14].

Table 1. Articles in the UNCRPD resolutions [10].

Article	People with disabilities have the right to:
9	Accessibility
19	Living independently and being included in the community
20	Personal mobility
24	Education
27	Work and employment
28	Adequate standard of living and social protection
29	Participation in political and public life
30	Participation in cultural life, recreation, leisure and sport

Table 2. Examples of national legislation affecting accessibility for the disabled.

Country	Legislation
United States	1990: Americans with Disabilities Act [7] 2010: Accessibility Guidelines for Buildings and Facilities [6]
United Kingdom	1995: The UK Disability Discrimination Act (DDA) 2000: Disability Rights Commission (DRC) established 2010: the Equality Act [15]
Australia	1992: Australian Disability Discrimination Act (DDA) 2002: Disability Standards for Accessible Public Transport 2005: Disability Standards for Education 2010: Australian Disability Access to Premises – Buildings Standard [12]
Germany	DIN 18040 barrier-free constructions [6]

Common failings of national legislation include:

- A disconnect between building practitioners' implementation and legislative requirements. This is because of confusion about compliance requirements and because of the cost of compliance. The legislation tends to give examples of compliance in common areas (such as parking spaces and toilets for the disabled) and practitioners do not extend these to other aspects of the building [12].
- Lack of specifications and accountability for access to the environment around public buildings and around neighbourhoods. Since nobody has responsibility for these, they are often ignored. This means that the disabled can often not get to the immediate vicinity of a building even though they may be able to move around inside the actual building [12,16].
- Failure to address the inaccessibility of historical buildings, coupled with vague requirements to make 'reasonable adjustments' to improve accessibility [11,15].
- Failure to maintain accessibility in the BE, for example, keeping indoor and outdoor paths free from obstacles [8,11, 17].
- A lack of understanding of the needs of disabled people and a failure to consult them on new BE construction [9,15].

In summary, universal access to the BE is a laudable goal but it is a long way from becoming a reality, even in developed countries. There are too many different types of disability to design a 'one size fits all' BE. The disabilities are not well-understood by building practitioners and the disabled are usually not consulted in the planning stage of new designs. The compliance legislation is difficult to understand, non-inclusive and costly to implement. This article looks at the problem from the perspective of one particular disabled group, namely manual wheelchair (MWC) users. It discusses their characteristics, the compliance requirements that have been set up to address their needs and their everyday experience as they try to function in the BE. The aim is to give building practitioners a more informed perspective on the difficulties faced by MWC users. This may provide motivation for improvement beyond the minimum required to satisfy compliance.

2. Research Methodology

A systematic review of academic literature was conducted using Google Scholar and Massey University library Discover search engines with key words including wheelchair, accessibility, universal design, disability, accessibility standard, mobility, transportation, tourism, routing, navigation and cost benefit analysis. A screening of the resulting literature and citations of relevant articles resulted in 44 articles, of which most are academic articles published within the last 10 years. Also included are national and international reports on disability statistics, historical population statistics, standards and building code regulations. The search was limited to only articles written in English.

3. Challenges for MWC Users in Accessing the Built Environment

3.1. Intrinsic Challenges from Using a Manual Wheelchair

This study looks at the accessibility challenges faced by MWC users, so the first question to consider is what is the size of this particular population? This is complicated because most statistics on wheelchair use include all types of wheeled mobility devices (both manual and powered wheelchairs and scooters) and some sources only cite users that are not in institutions. Additionally, the data is cited at different time periods. Table 3 summarises the few published statistics on the number of wheelchair users together with population estimates in 5 countries.

70 to 90% of all wheelchairs are the manual type [18-20]. Over 50% of wheelchair users are aged 65 or older [13,21] which means that data on community-based wheelchair users is likely to be a low estimate of the population size since it excludes those in aged-care facilities. The U.S. Census data [22] is likely to be the most reliable data (row 1 in Table 3) and shows that non-institutionalized MWC

users make up 0.9% of the US population. Therefore, the total MWC users are likely to be about 1% of the population. This will increase with the predicted increase in the ageing population [15].

Table 3. Statistics on the number of wheelchair users (WCUs) of all types with manual wheelchair data shown in bold text.

#	Country	Data and source	WCUs (%)
1	United States	Smith <i>et al.</i> [13] cites 2010 census data: 3.6 million WCUs (all types) Premont <i>et al.</i> [23] cites 2009 data: 2.7 M non-institutionalized manual WCUs	1.2 0.9
		Population about 308 M [22]	
2	United Kingdom	Smith <i>et al.</i> [13] cites 2005 study: 640 K to 710 K WCUs in the United Kingdom Population about 60 M [24]	1.1
3	Canada	Smith <i>et al.</i> [25] cites 2012 data: 288.80 K community-dwelling WC and Scooter users with 197.56 K manual WCUs	0.8 0.6
		Population in 2012: 35 M [26]	
4	France	Best [18] cites 2008 data: 361.5 K WCUs and a population of 58 M	0.6
5	Netherlands	Best [18] cites 2002 data: 152.4 K WCUs and a population of 16 M	1.0

K: thousand M: million

The next aspect to consider is the intrinsic limitations arising from being in a MWC. The first limitation stems from the medical condition that led to wheelchair use and the severity of the condition [27-29]. This results in a range of disabilities, from paraplegia (loss of lower body function) to tetraplegia (loss of arms, legs and torso function) with many associated secondary health problems [30]. The second limitation stems from prolonged use of the MWC itself and the resulting additional health issues. The upper body muscles used to propel the MWC are much smaller than those used for walking or cycling [31]. In addition, only about 25-40% of the propulsion stroke drives the MWC; the rest of the stroke is spent in re-positioning the hands for the next push [32]. The grasp-push-release cycle is repeated once every second at normal travel speeds and puts enormous repetitive stresses on the shoulder, elbow and hand joints [33]. Consequently, 37.5 to 78.0% of MWC users suffer from shoulder pain and up to 43% of MWC users have hand and elbow pain [34-36]. Increasing pain reduces the use of the MWC, decreasing the user's social interaction and physical (cardiovascular) activity. The consequence is steadily decreasing health and worsening quality of life (QOL) [27,30,33,37,38].

3.2. Code Compliance

This section looks at some of the common standards that exist to improve accessibility in the BE for MWC users. It focusses on the outdoor environment since this is far more challenging to MWC users than the indoor environment. It then looks at the main reasons why the BE fails to meet accessibility standards and the steps that can be taken to improve the situation.

3.2.1. Standards on accessibility for MWC users. Typically, the BE has standards on path widths, slopes, cross slopes and discontinuities such as kerb cuts and doorway transitions. The standards vary for different countries so the New Zealand standard, NZS 4121:2001 Design for access and mobility –

Buildings and associated facilities, is used as an exemplar [39]. It provides the practical guidelines that must be followed in order for the BE to comply with the New Zealand Building Code (NZBC) Clause D on Access. Table 4 lists some typical guidelines.

Table 4. NZS4121:2001 guidelines relating to MWC accessibility in the built environment [39].

#	Feature	Specification
1	Path width	Clear widths of accessible paths must be at least 1,200 mm. Clear widths allowing two wheelchairs to pass comfortably must be at least 1,800 mm.
2	Door opening	Door openings must be at least 760 mm wide.
3	Cross slope	Cross slopes must have gradients of not more than 1:50 (1.15 degrees).
4	Slope	Slopes on paths and ramps ^a must have gradients of not more than 1:12 (4.76 degrees). Level rest areas must be provided at intervals not exceeding 18 m and must be at least 1,200 mm in length.
5	Ramp landing	Level platforms or landings with a clear length of 1,200 mm must be provided at the top and bottom of the ramp, wherever there is a change in direction, wherever doors open off them and at intervals of not more than 9,000 mm.
6	Kerb ramps	Kerb ramps must have a slope of not more than 1:8 (7.13 degrees).
7	Thresholds	Changes in threshold level must be smaller than 20 mm and marked with contrasting colour strips. Changes in threshold level that are greater than 20 mm must be provided with a ramp.
8	Car park	Surface must be stable, firm, slip resistant and level (flatter than 1:50).

^a: If the gradient is steeper than 1:20 then the path is deemed to be a ramp

The American ADA accessibility guidelines [7] are similar to these with slightly narrower path width requirements (915 mm for paths and 1,065 mm for ramps, instead of 1,200 mm), a slightly steeper cross slope (1:48 instead of 1:50) and slightly longer clear lengths for ramp landings (1,525 mm instead of 1,200 mm). It also recognises that steeper slopes are acceptable to get up small height changes over short distances [33]. The standards are steadily improving, for example in the USA, new sidewalks must have a clear width of 1,500 mm [8].

3.2.2. Problems with the standards. While standards are a good first step towards making the BE more accessible to MWC users, the cost to implement them is a major constraint for building professionals. There is little/no responsibility for maintaining standards on many outdoor parts of the BE and certain buildings (such as heritage buildings and domestic dwellings) are often excluded from the compliance regulations.

Tyler [17] notes that despite a maximum permissible cross slope on outdoor paths, the reality is that measured cross slope varies enormously and changes over time as the soil settles. This may seem trivial to the able-bodied, who are usually unaware of the path cross slope as they walk and who can easily climb steps. However, it can be devastating for the MWC user; they have to push harder on one side of the wheelchair to compensate for the cross slope and risk damaging one arm and they may lack the strength to push themselves up a ramp that is steeper than that required by the standard [40]. Holloway *et al.* [34] compared the peak propulsive forces required on a 2.5% (1.4 degree) cross slope and on a 6.5% (3.72 degree) ramp and found them to be 1.4 and 4.1 times greater respectively than the peak force required on a level surface. Bertocci *et al.* [41] confirmed the finding that propelling a

MWC up a steep slope requires greater shoulder forces and moments that can be very problematic for those with shoulder pain. Kim *et al.* [33] and Gagnon *et al.* [16] note that in the U.S., slopes may be steeper than 1:12 for existing buildings and where space is limited, but that they should never be steeper than 1:8 (7.13 degrees). However, steeper slopes are common and the standards do not apply to areas such as private dwellings, public infrastructure and pedestrian environments [12].

There is a host of other problems with accessibility standards. These include ill-defined boundaries where nobody is responsible, the incorrect assumption that examples of compliance are the entire requirements, standards written in legal language that is hard to understand and little/no enforcement [12].

The biggest barrier to better accessibility in the BE is the cost; building practitioners operate in a competitive world and that means doing the minimum required to satisfy the standards. Terashima and Clark [42] review the economic benefits of going beyond the minimum requirements in terms of market potential and cost savings. They show that the tourism industry is likely to show the greatest direct cost benefit from improving accessibility and capturing the disabled persons' market. In the transportation industry, improved accessibility (for example, from better crosswalks and wider train doors) translates into direct benefits such as greater use by the disabled and also indirect cost savings in terms of time saved from using the improved transport infrastructure. There are a few stated preference surveys, not specifically restricted to MWC users, that show that people appear to be willing to pay more for improved accessibility features such as provision of automatic doors in public buildings and more accessible housing [42]. In the previous section, we saw that improved accessibility allows MWC users more participation in society and therefore a better QOL and this probably has a cost saving in terms of reduced medical care. Unfortunately, this is not a primary concern for the building industry.

3.2.3. Improving accessibility through standards. One of the first steps in improving accessibility is to have appropriate metrics to assess the BE's accessibility. There are generic access auditing tools, not specifically for MWC users but for all types of disabled access, for example [12]:

- ADA Checklist for Existing Facilities: to identify the main problems with access in US facilities.
- Accessibility Instruments Measuring Fitness and Recreation Environments (AIMFREE): to assess health clubs and gyms in the US.
- The Building Inclusiveness Assessment Score (BIAS): to assess university building disability inclusiveness, with sub-scores for physical disability inclusion (PDIS) and Visual impairment inclusion (VIIS) [3].
- Universal Mobility Index (UMI): to provide a quantitative measure of equity of access across all aspects of the BE.

The aim of these tools is to identify areas where accessibility can be improved and to follow this with regular monitoring of the remediation efforts. Once again, cost is the biggest barrier to using the auditing tools and to prioritizing the remediation. A disadvantage of the first three tools is that they use long, complicated checklists and they are only used for buildings and their immediate surroundings, instead of the wider BE [3]. Another of their limitations is that they are developed and used without input from disabled users. The UMI is an exception; it looks at the wider BE and relies on neighbourhood accessibility assessment done by people with disability.

The scale of inaccessibility in the BE is not known and, without valid measures, it is hard to judge the extent to which it is improving. However, there is general consensus that the BE continues to fail the disabled in this area [2,9,12]. Building practitioners need to engage with the disabled community in order to get a better understanding of the challenges they face and to develop better access auditing tools. Ideally, this will provide the motivation to improve accessibility beyond the level that satisfies code compliance, but Bromley *et al.* [15] note that voluntary action is rare. Realistically, the disabled community needs to push harder to drive government policies towards stricter accessibility standards, better monitoring and bigger penalties for non-compliance [42].

3.3. *The experience of manual wheelchair users in the built environment*

Just like able-bodied people, MWC users use navigation tools to plan their journeys. These include general tools (used by everyone) such as Google maps pedestrian routing tool, Google Street View, OpenRouteService, Routino and Yelp (which has information on wheelchair access) and tools specifically for use by mobility-impaired people, such as Handimap, AXSMap, WheelMap and MoTAg. There are several reviews of their usefulness to MWC users to whom the effort and safety of a route is often more important than just the identification of the shortest route [8,11,20,22,43]. There is also research into other tools, such as personalized route systems where individuals rank barriers such as path surface and traffic and the route is marked with the rankings [44]. However, these are so labour-intensive that they are limited to small public areas (such as a university campus) and do not necessarily capture information that matches the very varied capabilities of all MWC users. Zeng *et al.* [6] note that accessibility tools need to be developed with the input of MWC users because able-bodied people do not have a good understanding of what is challenging for a person in a wheelchair. For this reason, many MWC users rely upon the advice from other MWC users and caregivers when deciding on what route to use and do a ‘practice run’ on routes that they may need to use in the future [8]. Vozikis [11] discusses the absolute necessity for an entire route to have a continuous ‘chain of accessibility’; if one link or part of the route is inaccessible to a MWC user, then the entire route becomes unusable. A link may be broken by temporary blockage for building work, or it may gradually break from lack of maintenance.

For the MWC user, the ideal path is level (without slope in the direction of travel and without cross slope), has a smooth surface and is wide enough to manoeuvre the wheelchair. The biggest problems MWC users face on outdoor paths are steep slopes and cross slopes, bumps in the path (for example from tree roots and cracks), steps, poor/no kerb cuts and the inclusion of objects such as lighting, benches and plants that reduce the available path width [8,20]. When these problems are compounded, and a path has both a steep slope and a steep cross slope, the increased challenge will make many MWC users avoid them [28]. Indoors, the main barriers are door handles and counters that are too high for a seated person, manual doors and inadequate provision of changing rooms and lifts/elevators [2,15].

Accessibility is improving rapidly for MWC users and there are government initiatives such as the Participatory Action Design initiative, in the UK, which uses consultation from different user groups in the design phase of new public buildings [15]. Vozikis [11] notes that old buildings still perform badly and that a lack of monitoring and maintenance leads to common problems such as lifts being out of order, toilets for the disabled being used for material storage (reducing the space available to manoeuvre the wheelchair) and disabled parking being used by the general public. Lau *et al.* [3] reports that higher education buildings often lack seating space and adequately wide passages for MWC users and tend to have non-inclusive evacuation plans for them.

4. Findings and Discussion

Historically, the BE developed without considering the needs of the disabled. The 2006 United Nations Convention on the Rights of Persons with Disabilities specified their right to accessibility, independent living, community inclusion, personal mobility, education, work and participation in public activities (Table 1). Countries have developed legislation to address these rights (Table 2) and accessibility has improved. However, it remains limited by inadequate understanding of disabilities by building practitioners, lack of consultation in the planning stage of new designs, complex legislation language that is difficult to understand, non-inclusive and costly to implement. More legislation, maintenance and punitive consequences are needed to improve accessibility.

This review has shown that approximately 1% of the population uses a MWC to navigate the BE (Table 3). To address the needs of MWC users, there are accessibility standards on features such as path widths, ramps, cross slopes, thresholds, kerbs and parking (Table 4) and, again these are steadily improving. However, cost remains the most significant barrier to implementing the standards and means that practitioners design accessible features that just meet the minimum required by the

standards. The tourism and transportation sectors can increase their revenue by including the disabled market but the other indirect benefits, such as improved health and quality of life, are not regarded as the responsibility of building practitioners. The tools used by MWC users to navigate the BE need to improve to capture the barriers that are significant to this demographic, with its wide range in physical capability. In particular, the tools need to show the effort required to use routes and to flag inaccessible portions that will make an entire route impassable.

5. Conclusions and Further Research

When MWC users struggle to access the BE this is a health risk that lessens their social participation and diminishes their quality of life. Access is made easier by building standards, but these are expensive to implement so they are limited to only certain portions of the BE and are poorly regulated. The current standards are complex and non-inclusive; showing a few examples of compliance that are often mistaken for comprehensive compliance. They need to be improved by being written in simple language and they need to be extended to the 'grey areas' where they do not currently apply. Building practitioners operate in a competitive world and it is unrealistic to expect them to operate altruistically. Therefore, compliance with standards needs to be regularly monitored and penalties for non-compliance need to be enforced. The standards themselves should be improved with input from MWC users in order to address the real challenges they face. This review has also shown that the input of MWC users is vital to the design of new, more accessible environments and to the development of access audit tools and navigation tools that accurately capture the experience of these people. Improved accessibility to the built environment for MWC users will be achieved only through these changes.

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