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Alborz Ahosseini
Aalborg University

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Alborz Ahosseini [a,b]
[a] *Ellwand Co., Denmark*
[b] *In cooperation with Town, Housing and Property, Danish Building Research Institute, Aalborg University, Copenhagen, Denmark*

Abstract. With the speed of emerging technologies, building regulations and norms need an update to reflect the evolution in mobility aids. This research is suggesting new proposals for norms and standards for Maneuvering Area, Corridors and Lobbies for Wheeled Mobility Aid users by taking the evolution in new-wheeled mobility aids into account.

Keywords. Wheeled Mobility Aid users, Maneuvering Area, Corridors and Lobbies

1. Introduction

World is evolving rapidly, and new accessibility equipment and devices are being introduced which makes life easier for the people with disabilities. However, the rapid developments in the evolution of accessibility equipment may not always be coordinated with the existing accessibility norms and standards. The gap between accessibility provisions in built environments and developments in accessibility equipment is increasing by not taking the evolution of assistive equipment into account. By having a future orientated view on the development of accessibility equipment, some of the existing accessibility norms and provisions may thus require to change significantly. One of the important assistive mobility device types is Wheeled Mobility Device (WMD) or Wheeled Mobility Aid (WMA) that considered most effective way of improving the impact of mobility limitations for many people with mobility impairments. The design of wheeled mobility aids is rapidly evolving, and therefore the relevant accessibility standards for built environments need reconsideration respectively to cover future developments. The evolution in wheeled mobility device have meanings in different parts of the built environment such as building facilities, access to the building, entrance to the building, parking spaces and etc. The main goal of this study is to investigate and find new proposals for norms/standards related to Maneuvering Area, Corridors and Lobbies for Wheeled Mobility Aid users based on the evolution in mobility aids.

2. Methodology (Collection of Current Wheeled Mobility Aids in Market)

In order to achieve this goal, a list of existing mobility devices and their dimensions are prepared which are in use right now in Danish market and globally. The dimensions of the mobility devises presented in this research are mainly taken from two different sources [1-2], [7-10]:

- Product brochures and online broachers of devices existing on the market at present in Denmark and globally
- Devices that are used as a reference in benchmark literatures and building regulations.

Maximum possible dimension of new mobility device is derived from the mentioned list to be used as a benchmark dimension in the current article. The new proposed measurements for Maneuvering Area, Corridors and Lobbies for Wheeled Mobility Aid users are calculated/simulated based on the maximum possible dimension of the current mobility device; the measures of a human body is added to this dimension to make it correspondent to the actual scenarios. This corresponds to the path of a wheeled mobility aid user entering a lobby/corridor until exiting it using a Maneuvering Area with a maximum-size wheelchair.

2.1. Denmark's current wheeled mobility devises

In the following tables, dimensions of some new mobility devises, which are currently on the Danish market, are listed. The tables are categorized in adult, children and bariatric". Full tables are available in in the appendix I of [12]. The models mentioned in these tables are selected based on their size. Devices are chosen from the most common devices on the market, and sorted by type from walker to scooter[1].

Table 1. Adults (between 18 and 65 of age)

Product type	Product name	Length (mm)	Width (mm)	Height (mm)	Turning Diameter +user (mm)
Walker	Malte Rollator str.4	920	800	1200	--
Manual wheelchair	Azalea Base	1070	720	1400	--
Manual wheelchair	Rea Azalea	1020	**770**	1250	--
Electric wheelchair	Invacare Mirage	1020	**820**	1250	--
Scooter	Mini Crosser Nordic 4-Wheels	**1390**	660	--	3180
Scooter		1360	660	--	2540

The dimensions of devices for two other types of person (children, bariatric) mentioned in Table 2 and table 3 in order to highlight the differences of the size of the devices. The dimensions of mobility devises in other countries than Denmark are shown in Table 4. However, as mentioned above, the focus of this study is on average-size adults and the devices that are currently available on the Danish market.

[1] All sizes are according to suppliers' information, but minor changes made on some of them to be consistent (for example radius to diameter or inch to millimeter etc.)

Unfortunately, there is not a precise statistic of mobility aids and their users or any classified information about them now in Denmark. These four tables [1-4] show just some examples of products that have at least maximum dimension in one of length, width, height or turning diameter. A full table presented in appendix I of [12].

Table 2. Children (under 18 years of age); this is a summary of table 2 in the appendix I of [12]

Product type	Product name	Length (mm)	Width (mm)	Height (mm)	Turning Diameter +user (mm)
Walker	Buddy Roamer 3 & 4	900	800	--	--
Walker	Mustang sz 4 Blue	1100	700	--	--
Walker	Pegasus Trækrollator	755	660	725	--
Manual wheelchair	Euro chair Avanti Junior	880	560	--	--
Electric wheelchair	A200 Skipp	850	570	--	1100

Table 3. Bariatric (BMI over 30); this is a summary of table 3 in the appendix I of [12]

Product type	Product name	Length (mm)	Width (mm)	Height (mm)	Turning Diameter +user (mm)
Walker	XXL-Rehab Rollator	845	710	1300	--
Manual wheelchair	Azalea Max	1120	910	1240	--
Electric wheelchair	PUMA 40 Front-W-Drive	1190	655	--	600
Scooter	Lindebjerg LM – 600	1550	760	--	1500

2.2. Worlds current wheeled mobility devises

In this table, dimensions of some of the current mobility aids in the world are presented.

Table 4. Children (under 18 years of age); this is a summary of table 2 in the appendix I of [12]

Product type	Product name	Length (mm)	Width (mm)	Height (mm)	Turning Diameter(mm)
Wheeled Walker	Drive Deluxe3-Wheels	965	635	610	--
Wheeled Walker	Excel Translator	--	686	914	--
Manual wheelchair	Karman Ergo Flight	965	457	914	--
Manual wheelchair	Pro-basics Wide Seat Bariatric	--	813	--	--
Electric wheelchair	Allure R – HP6R	1170	620	1205	1320
Scooter	New 2012 Vita S12X – Monster	1651	812		2700
Scooter	EV Rider Royale 4	1575	914	1346	--
Neurologist wheelchair	Neurologist wheelchair	1000	480	1370	--

2.3. Maximum dimensions of mobility aids

The dimensions in the following tables are elicited from the results of Tables [1-4] and the reference books; and they are sorted by size (largest to smallest). This gives an overview of the dimension of the current mobility devises in the most valid references (links, books) and on the market.

Table 5. Maximum Length of mobility aids

Source	Maximum (mm)	Type
Human scale 8b – Public Space	1830	Manual wheelchair + user + helper
SBi Guidelines 222	1750	Comfort-wheelchair + user + helper
Table 4	1651	Scooter
SBi Guidelines 222	1500	Electric scooter + user
Table 1	1390	Scooter
SBi Guidelines 222	1300	Electric wheelchair + user
Table 2	1190	Electric wheelchair
Building Access Handbook 2007	1105	Manual wheelchair
Building Access Handbook 2007	1000	Walker + user

Table 6. Maximum Width of mobility aids

Source	Maximum (mm)	Type
Table 4	914	Scooter
Table 1	820	Wheelchair
Table 1	770	Manual wheelchair
Human scale 8b – Public Space	760	Manual wheelchair + user + helper
SBi Guidelines 222	750	Comfort-wheelchair + user + helper
SBi Guidelines 222	700	Electric wheelchair + user
SBi Guidelines 222	700	Scooter
Building Access Handbook 2007	700	Manual wheelchair
SBi Guidelines 222	600	Walker

Table 7. Maximum Occupied (Required) Turning Area of mobility aids

Source	Maximum (mm)	Type
SBi Guidelines 222	2250x2250	Comfort-wheelchair + user + helper
SBi Guidelines 222	1850x1850	Electric wheelchair + user
SBi Guidelines 222	1750x1750	Scooter
SBi Guidelines 222	1300x1300	Walker

3. Maximum Dimensions of New Mobility Aid (hypothetical device)

Various mobility devises have different dimensions; some are longer and some are wider. In order to find the maximum dimensions of mobility devises that are currently in use, the maximum length and width of the mobility devises are derived from tables 1-4. This helps us finding the dimension of a device that has the maximum width and length. That corresponds to the length of scooter "Mini Crosser Nordic" (that has the maximum length) and the width of electric-wheelchair "Rea Azalea" (that has the maximum width) .Maximum driven dimension is 1390 x 820 mm (length x width) as shown in Figure 1.

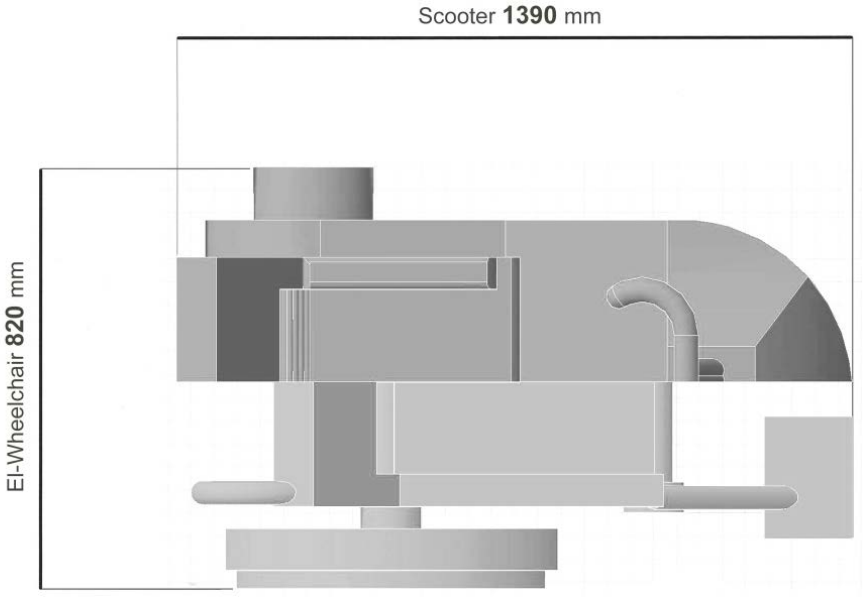

Figure 1. hypothetical Mobility device with maximum dimensions[2]

In order to find the maximum width of the wheelchair plus the user, two different scenarios for manual-wheelchair and electric-wheelchair are investigated. Since the maximum Width is the width of the electric-wheelchair plus user, an approx. of 1100 mm is considered which is assumed the maximum width of wheelchairs in this research (maximum width plus a margin). For the maximum length, the maximum length of "Mini Crosser Nordic 4-W" scooter (1390 mm) is considered as shown in Figure 2.

[2] Three devices used in this research to calculate the maximum dimension of a hypothetical device (Out of devices summarized in Table 1) shown in Appendix II, Figure i, Figure ii and Figure iii of [12].

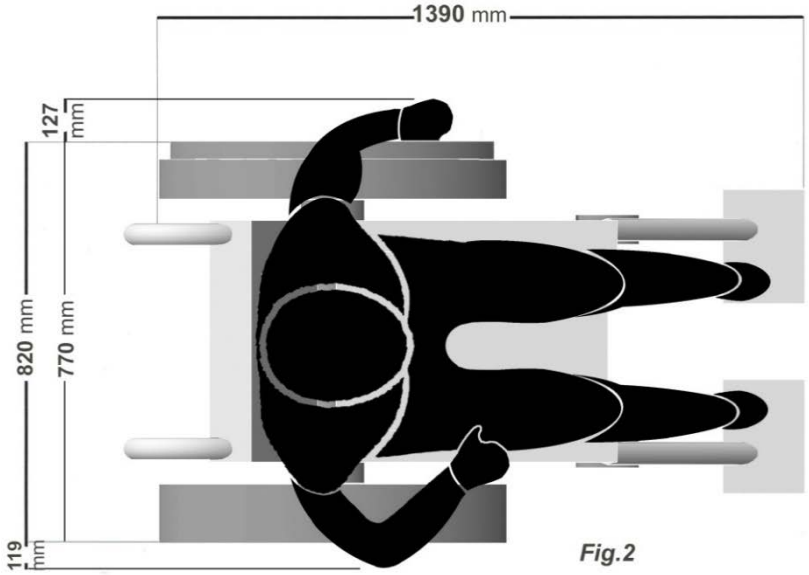

Figure 2. Mobility device with maximum dimensions plus the user[3]

3.1. Dimensions of maneuvering area; based on new mobility device dimensions

A maneuvering space (180° around the axel) is suggested in front of entrance/elevator and/or two ends of corridors to give possibility of turning around and return back if all rooms in corridor are locked and there is no way on the other side of corridor to exit.

The simulations of the maneuvering area are done in "AutoCAD" .The center of maneuvering space is considered the center of the mobility device in simulations. Simulations show that:

> Minimum maneuvering space is 2100 x 2100 millimeter for a scooter with user as well as a wheelchair with user and helper. Minimum maneuvering space for electric wheelchair with user is 1750 x 1750 millimeter. That also covers manual wheelchair including user.

[3] The body size of the user and the helper is based on the real body dimensions driven from [5, 6]. The equipment they utilize on their chairs and the accessories they add to them is not considered in the current paper and is covered in another scientific paper of the Author.

3.1.1. Maneuvering space (180° around the axel):

Table 8. Dimension of turning area

Source	Dimension (mm)	Info.
Human scale 8b – Public Space	2130 x 2130	Manual wheelchair + user + helper
New suggestion	2100 x 2100	Wheelchair + user + helper Scooter + user
New suggestion	1750 x 1750	Wheelchair + user
ISO 2011	1600 x 2150	In a corridor
ISO 2011	1500 x 2000	Outward opening door
BR 10 3.2.1 stk. 2	1500 x 1700	Outward opening door
BR 10 3.2.1 stk. 2	1500 x 1500	Inward opening door
SBI Guidelines 222	1500 x 1500	
ISO 2011	1500 x 1500	Between doors of a lobby

4. Corridors and Lobbies

The detailed calculations for the dimensions of corridors and lobbies presented in below sub-section. Based on the calculations, the new suggested dimensions for the corridors and lobbies are presented in Table 9, Table 10 and are compared with the current benchmark literature and building regulations.

4.1. Calculation of dimensions of corridors based on new mobility device dimensions

Three different scenarios defined for mobility aids in corridors:

- When the corridor has two-way traffic and there are two devices standing beside or passing each other: In this case, the minimum width of the corridor should be twice the maximum size of wheeled mobility aids which is 2 x 1100 mm ≈ 2200 mm (Figure 3 A).

- When a wheelchair and a person are side by side: It is a two-way traffic when mobility device/devices is/are in one direction and (an) average size person is passing by or coming from the other direction. For calculating a normal corridor width, the maximum width of the mobility device added to the shoulder size of the other person in the corridor. In this case, the minimum width of the corridor increased to 1500 mm that is 1100 mm (for the wheelchair) + 400 mm (for shoulder size)

Note: 390 mm ≈ 400 mm is the shoulder size of a strong man [5]. (Figure 3 B)

- When the corridor is one way: In this case, the minimum required width is the same as the maximum width of the mobility device that is 1100mm. (Figure 3 C)

Short length corridors with few passengers can use one way (it means one person at a time can pass the corridor).

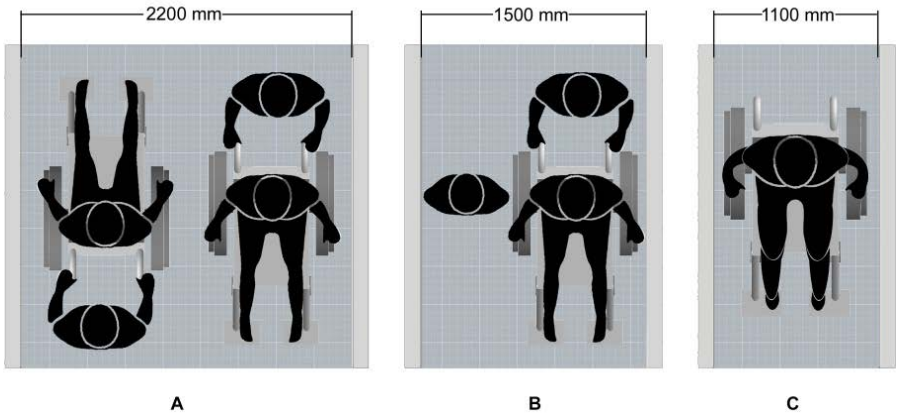

Figure 3. Configuration of wheelchair users and helper in corridors

4.1.1. Comparison of Current Dimensions and New Suggested dimensions for Corridors

The width of the corridors from different benchmark literature and standards are compared with the proposals made in the current article:

Table 9. Width of Corridors

Source	Minimum	Info.

New suggestion (Fig. 3 A)	**2200 mm**	Two-way traffic
SBi Guidelines 230	1800 mm	Quality Standard A
SBi Guidelines 222	1800 mm	Quality Standard A
ISO 2011	1800 mm	Constant two-way traffic
BS 8300:2009 + A1:2010	1800 mm	Two-way traffic
Human Scale (8b)-Public Space	1630 mm	Two-way traffic
The measure of man and woman	1525 mm	Two-way traffic
New suggestion (Fig. 3 B)	**1500 mm**	Two-way traffic
SBi Guidelines 230	1500 mm	Quality Standard B
SBi Guidelines 222	1500 mm	Quality Standard B
ISO 2011	1500 mm	Frequent two-way traffic
SBi Guidelines 230	1300 mm	Quality Standard C
ISO 2011	1200 mm	Infrequent two-way traffic
BS 8300:2009 + A1:2010	1200 mm	One-way traffic
New suggestion (Fig. 3 C)	**1100 mm**	One-way traffic
SBi Guidelines 222	1000 mm	Quality Standard C
The measure of man and woman	915 mm	One-way traffic
Human Scale (8b)-Public Space	910 mm	One-way traffic

4.2. Calculation of dimensions of lobbies based on new mobility device.

Three different scenarios are defined for the mobility aids in lobbies with “single-leaf single-swing door”:

- When both doors open inward: In this case, minimum required length is the maximum length of the mobility device (1400mm) and a margin (100 mm) added to twice minimum suggested door size (1100 mm). It is in total a minimum of 3700 mm. (Figure 4 A)
- When one of the doors open inward: In this case, the minimum required length is maximum length of mobility device (1400mm) and a margin (100 mm) added to minimum suggested door size (1100 mm). It is in total a minimum of 2600 mm. (Figure 4 B)
- When both doors open outward: In this case, the minimum required length is the same as the maximum length of the mobility device (1400 mm) plus a margin of 100 mm. It is in total a minimum of 1500 mm. (Figure 4 C)

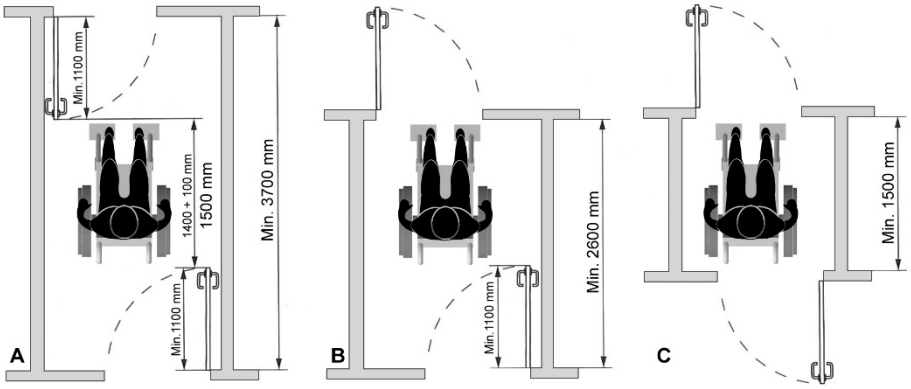

Figure 4. Configuration of wheelchair users in lobbies

4.2.1. Comparison of Current and New Suggested dimensions for lobbies

The length of lobbies from different benchmark literature and standards are compared with the proposals made in the current article:

Source	Minimum	Info.
New suggestion (Figure. 4 A)	**3700 mm**	Two-door lobby
ISO 2011	3200 mm*	Two-door lobby
New suggestion (Figure. 4 B)	**2600 mm**	One-door lobby
ISO 2011	2350 mm**	One-door lobby
New suggestion (Figure. 4 C)	**1500 mm**	Outward opening door
ISO 2011	1500 mm	Outward opening door

Table 10. Length of Lobbies

* 1500 mm + (2xDoor width) = 1500+1700
**1500 mm + Door width (850 mm)

5. Conclusion

New proposals are made for Maneuvering Area, Corridors and Lobbies based on the new mobility aids dimension. These proposals are compared with the norms and standards that already exists in the reference books [1], [2], [3] and [10] concluded that:

Width of Corridors: The new suggested widths for the corridor based on this study (2200mm and 1500 mm) are wider than the proposed width (for the same type) in existing building regulations and benchmark literatures.

Length of Lobbies: The new suggested length for both one-door and two-door lobbies with single-leaf single-swing doors (1500 mm, 2600 mm & 3700 mm) are longer than current standards.

Maneuvering space and Dimension of turning area: The suggested dimension of turning area in other benchmark litterateurs and building regulations are smaller than the new suggested area in this study (2100 x 2100 mm & 1750 x 1750 mm) except Human scale (8b)-Public space.

From the above explanation and comparison, it is concluded that calculating and proposing new dimensions for Maneuvering Area, Corridors and Lobbies based on the new mobility device dimensions is vital; since as shown in the current research, some of the current dimensions are not wide/long enough to accommodate the new mobility aids. On the other hand, some of the other dimensions are wider/longer than the required dimensions. This will definitely be a beneficial step toward making the buildings accessible for all based on the new mobility device dimensions.

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