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Design for All – Design for Disabled: How important is anthropometry?

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Abstract.
BACKGROUND: Design for All or Universal Design is a relatively new domain in Ergonomics. With globally ageing populations, it has however recently gained significant interest.
OBJECTIVE: This position paper summarizes the outcomes of a workshop held at the virtual 21st Triennial Congress of the International Ergonomics Association. The paper expands the horizon of traditional Ergonomics into a domain where people are differently abled and establishes a platform for the essential needs of future ergonomic standards which are required to inform inclusive design guidelines, or Design for All, extending the range of users.
METHODS: The paper includes contributions from Asian, Australian, European and US workshop participants who are accessibility design experts in their respective geographic regions. The paper summarizes issues related to anthropometry in the Design for All, based on recent work in the US (Access board) and actual developments in various national and international accessibility standardization bodies, such as the Standards Australia/Standards New Zealand, the European Standardization Organization (EN 17210:2021; EN 17161:2019) and the International Organization for Standardization (ISO 21542:2021 and BS ISO 7176-5:2008).
CONCLUSIONS: The paper concludes that despite the identification of a significant gap in knowledge of the anthropometry of people with disabilities as far back as 1990, work towards bridging the gap and enabling ergonomic standardization has not progressed since then globally. The lack of standardization in anthropometric data on people with a physical disability continues to complicate provision of data for mobility and accessibility design and hampers accessibility standardization efforts.

Keywords: Universal Design, architectural accessibility, disabled persons, standardization, standards

1. Introduction

A ‘Design for All’ approach as per EN 17161 [1] or Universal Design approach extends the traditional limitations of Ergonomics by considering a population sub-group with special characteristics, which would normally not be included within the populations studied in Ergonomics.

While physical disability is an important part of Design for All, the concept typically relates to disability in Europe, Australia and India; in Japan, it has a broader approach, including the able-bodied elderly. Design for All also includes different cultural backgrounds and preferences of the greatest number of people possible.

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Australian Standard 1428.6 [2] is being developed by the Joint Standards Australia/Standards New Zealand Committee ME-064, Access for People with Disabilities. It supersedes several older accessibility requirements in the outdated AS 1428.2 [3] for enhanced and additional requirements of buildings and facilities. The standard is one of a series of five standards related to design for access and mobility in the built environment. The standard covers those elements of an accessible building or places not covered by AS 1428.1 [4] which is a legally mandatory standard for all buildings. Such elements can be fittings, furniture, and equipment, that are suitable for use by people with disabilities. The development and revision of the AS 1428.6 [2] and AS 1428.1 [4] standards in 2020 exposed significant shortfalls in anthropometric and functional data of people with disabilities and older workers. While this is not surprising, given that universal design is not a core element of Ergonomics, it imposes a serious risk to the implementation of ergonomic methods and EN 17161 [1] overall. Existing standards for the measurement of anthropometric data cannot be fully applied to people who routinely use wheelchairs. Existing data have been collected without using a consistent method and are thus extremely limited. Therefore, existing functional data, including static and dynamic dimensions are even more limited. Worldwide, no standard exists for the anthropometric measurement of people who cannot assume the standard standing or seated measurement postures. Therefore, no global database of anthropometric and functional characteristics is available to inform Design for All standards.

2. Objective

This paper seeks to provide a consolidated position and argument of selected international experts active in international standardization bodies. The experts aim to provide a united problem statement to be endorsed by the International Ergonomics Association.

3. Methods

The paper is based on a workshop which was held at the virtual 21st Triennial Congress of the International Ergonomics Association on 16th June 2021. The 90-minute workshop was conducted on a virtual platform and all contributions were made online. The workshop was structured into an introduction statement, five expert statements, two pre-recorded expert presentations and a summary.

In principle, the underlying method that was utilized in the workshop resembles an online focus group where an introductory call document replaced otherwise commonly used standardized questions. Given that a qualitative method was applied, this clarification is important when contextualizing the workshop outcomes, and it is intended to help understand the scientific framework of an online workshop at a time where many – forcibly - online studies may otherwise appear arbitrary. The workshop was guided, monitored online, and recorded by the workshop moderator. Structured focus groups are used to generate information on collective views about key issues and potential pathways towards solutions in the Design for All sector.

The two research questions that guided the workshop were:

1) A 'Design for All' approach or universal design approach extends the traditional limitation of Ergonomics by considering a population subgroup with special characteristics, which would normally not be included within the population studied in Ergonomics. Is there a gap in our knowledge of anthropometric and functional data of the disabled population that poses a risk to the universal design approach?
2) While universal design is not a core element of Ergonomics, we aim at implementing ergonomic methods within the paradigm. Can existing standards for the measure of anthropometric data be fully applied to the disabled, and specifically wheelchair bound population in the absence of a worldwide standard for the measurement of disabled anthropometric data?

Invited experts for the workshop were Associate Professor Gunther Paul (James Cook University, Australia), an active committee member of the AS/NZS ME-064 workgroup; Dr Bruce Bradtmiller (Anthrotech, USA) providing a statement on his work for the US Access Board on anthropometry of people with disabilities; Dr Nana Itoh (AIST, National Institute of Advanced Industrial Science and Technology, Japan), an active committee member of the ISO TC159 working group for standardization of people with special needs; Isabella Tiziana Steffan (Studio Steffan, Italy, EU), an active committee member of the CEN/CENELEC (European Standardization

Organization) work on a new European standard as well as two technical reports on accessibility of the built environment following a Design for All approach; and Richard Bowman (Intertile Research Pty Ltd, Australia) who has chaired the Standards Australia committee on the slip resistance of pedestrian surfaces since 1991. While Bowman observed that the lack of traction demand data for cohorts with specific disabilities created design challenges when seeking to ensure that floors would be sufficiently slip resistant for all users over economically reasonable life cycles, this accessibility related finding also indirectly pointed to a lack of anthropometric data.

4. Results and discussion

In Australia, the suite of accessibility standards consists of AS 1428.1-2009 [4] 'Design for access and mobility, Part1; General requirements for access', which is undergoing revision; AS 1428.2-1992 [3] 'Design for access and mobility, Part2; Enhanced and additional requirements' which is obsolete and will be replaced by AS 1428.6 [2], 'Design for access and mobility, Part6; Fixtures and fittings', which is currently being drafted; AS/NZS 1428.4.1-2009 [5] 'Design for access and mobility, Part4.1; Means to assist the orientation of people with vision impairment – tactile ground surface indicators'; AS 1428.4.2-2018 [6] 'Design for access and mobility, Part4.2; Means to assist the orientation of people with vision impairment – wayfinding signs'; AS 1428.5-2010 [7] 'Design for access and mobility, Part5; Communication for people who are deaf or hearing impaired'; and AS 4299–1995 [8] 'Adaptable housing', which is pending revision.

Corresponding standards in Europe are the recently published [29] standard EN 17210:2021 'Accessibility and usability of the built environment – functional requirements' [9], with its accompanying technical specification documents CEN/TR 17621:2021 'Accessibility and usability of the built environment - Technical performance criteria and specifications' [10], and CEN/TR 17622:2021 'Accessibility and usability of the built environment - Conformity assessment' [11].

Internationally relevant standardization work has been coordinated in ISO/TC159 AG2, the Advisory Group on the coordination of accessibility, led by Susan Harker, which recently announced its dissolution; ISO/TC159 WG2, the Working Group Ergonomics for people with special requirements, led by Nana Itoh, which has been asked to take over the scope of AG2; and ISO/TC173/SC1 for wheelchairs. Equivalent international standards are ISO 21542:2021 'Building construction — Accessibility and usability of the built environment' [12], BS ISO 7176-5:2008 'Wheelchairs — Part 5; Determination of dimensions, mass and manoeuvring space' [13], and ISO/TR 13570-2:2014 'Wheelchairs — Part 2; Typical values and recommended limits of dimensions, mass and manoeuvring space', as determined in ISO 7176-5 [14].

Other applicable standards are ISO 24505:2016 'Ergonomics — Accessible design — Method for creating colour combinations taking account of age-related changes in human colour vision' [15] and ISO 28803:2012 'Ergonomics of the physical environment — Application of International Standards to people with special requirements' [16].

While all accessibility and mobility standards suggest a large amount of target data, such as door openings, ramp angles, handlebar heights etc. for many buildings, fixtures, fittings or furniture designs, they entirely depend on empirical, selection-based data from mostly very small studies with inconsistent methods. And while any one study may be representative of a particular type of disability (e.g., spinal cord injury), none of these studies could possibly be representative of people with every type of disability. Moreover, the required systems perspective of a combined user/medical device system has so far not been agreed upon or standardized, and thus must be seen as non-established. In contrast, anthropometric data for people who can assume a standardized posture as per ISO 7250-1, such as upright standing or upright sitting have been defined and standardized in enormous detail, which is represented in the expansive international suite of standards ISO 7250-1:2017 'Basic human body measurements for technological design – Part1; Body measurement definitions and landmarks' [17]; ISO 7250-2:2010 'Basic human body measurements for technological design – Part2; Statistical summaries of body measurements from national populations' [18]; ISO 7250-3:2015 'Basic human body measurements for technological design – Part3; Worldwide and regional design ranges for use in product standards' [19]; ISO 14738:2002 'Safety of machinery - Anthropometric requirements for the design of workstations at machinery' [20]; ISO 15534-1:2000 'Ergonomic design for the safety of machinery — Part 1; Principles for determining the dimensions required for openings for whole-body access into machinery' [21]; ISO 15534-2:2000 'Ergonomic design for the safety of machinery — Part 2; Principles for determining the dimensions required for access openings' [22]; ISO 15534-3:2000 'Ergonomic design for the safety of machinery — Part 3; Anthropometric data' [23]; ISO 15535:2012 'General requirements for establishing anthropometric databases' [24]; ISO 15536-1:2005 'Ergonomics — Computer manikins and body templates — Part 1; General requirements' [25]; ISO 15536-2:2007 'Ergonomics — Computer manikins and body templates — Part 2; Verification of functions and validation of dimensions for computer manikin systems' [26]; ISO 20685-1:2018 '3-D scanning methodologies for internationally compatible anthropometric databases — Part 1; Evaluation protocol for body dimensions extracted from 3-D body scans' [27]; ISO 20685-2:2015 'Ergonomics — 3-D scanning methodologies for internationally compatible anthropometric databases — Part 2; Evaluation protocol of surface shape and repeatability of relative landmark positions' [28]; ISO/TR 9241-514:2020 'Ergonomics of human-system interaction — Part 514; Guidance for the application of anthropometric data in the ISO 9241-500 series' [29].

In 1990, Hobson and Molenbroek [30] stated that "in recent years increased emphasis has been placed on designing improved technical aids for physically disabled people", however they found the lack of appropriate anthropometric data for disabled persons a limiting factor. They aimed to develop an anthropometric database to help the Design for All, and thus studied a sample of 133 cerebral palsy participants and obtained 94 variables from each participant. Twenty quantitative variables were analysed, and the authors found that eleven of the 20 variables were not available from other published anthropometric sources. The measurements remained project-specific and were not progressed into international standardization. Thirteen years later, Paquet and Feathers [31] were commissioned by the US Access Board to evaluate structural anthropometric dimensions of adult wheelchair users to develop an anthropometric and functional ability database of that population. They made measurements on 121 manual and powered wheelchair users and sampled 36 body and wheelchair landmarks, from which they derived 31 body and wheelchair dimensions. This study is of particular interest because it pointed out significant differences between powered and manual wheelchair users, and it took a systems perspective where both wheelchair and body were considered as factors in identifying dimensional characteristics. While different from the study in 1990, this database again remained an insular development with no progress into a standard. In 2010 the US Access Board commissioned a follow-up to this project, which was conducted by the Center for Inclusive Design and Environmental Access (IDeA) at the University of Buffalo and is commonly known as the IDeA report [32]. The IDeA study may be considered the first systematic study into the anthropometry of people who use wheeled mobility aids. It identified several important and noteworthy findings that will have a general impact on all similar studies. The study emphasized the importance of multi-site studies because of large differences in samples; it found large differences in space requirements of manual wheelchair, power wheelchair and scooter users; the study also reported no generally accepted and shared definitions of anthropometric variables and resultant standards; moreover the study reported that different countries use different approaches for their standard development, and that reviewed standards had no comprehensive basis in evidence. The authors pointed out that some dimensions in standards did not correspond to measurable landmarks, and that the US reference wheelchair poorly represented the population. In particular, clear floor space, manoeuvring clearances, reach limits, operating forces and knee and toe clearances were identified in standards that did not accommodate a majority of the studied population.

Due to the uncertainty around previous studies and data, the Australian Building Codes Board commissioned a study by Caple et al. four years later in 2014 [33]. Again, this study took a unique approach by mixing lab studied and self-reported measurements, and it also worked with an inconsistent and very small sample size of 20–52 (from Sydney, Melbourne and Geelong, including 31 powered and 21 manual wheelchair participants), had a poor definition of data points and incomplete measurements. Unsurprisingly, this study produced different results compared to the much larger IDeA study.

Based on this history, it is not surprising to find a systematic literature review on 'Anthropometric data for wheelchair users" published by Bragança et al. in 2020 [34], which concludes that there is limited information available on wheelchair user anthropometry, that there is a lack of consistency between studies regarding measurements, samples and methods, and that methodological differences between studies make it difficult, if not impossible, to compare databases and derive valid targets for the design of space and equipment for this population.

Because of the lack in agreement, consistency, and ergonomic standardisation, it is left to the working groups of standardisation bodies to determine which data to recruit. In the absence of any clear direction or sufficient overlap in data, these groups tend to commission additional insular studies. To provide a few practical examples of the confused state of affairs in this regard, recommended toe clearance depth may vary from 190 mm in AS 1428.2 to 200 mm in AS 1428.1, 272 mm in the IDeA study [32] and up to 385 mm in the Caple report [33]. Equivalent toe clearance height guidance then differs from 280 mm in AS 1428.2 over 365 mm in the IDeA study [26] to 438 mm in the Caple report [33]. Knee (clearance) height for furniture is 820 ± 20 mm according to AS 1428.2 [3], 605 mm for the 95th percentile male Polish population [35], 735 mm for the 95th percentile male US population [31], and 760 mm according to the Caple report [33]. A comprehensive list of discrepancies between several studies has been listed in Bragança et al. [34].

Anthropometry is normally differentiated between children, adults and the elderly, and anthropometric data for children, including those with disability are equally important as adult anthropometric data. Some groups are currently working in this field, [e.g., CEN TC 122 WG 1 (TG 1) 'Anthropometric data of children', and ISO/NP 24396, NWIP 'Ergonomics for children - Guidelines for the design of products and services'], and ISO TC59/SC 16 'Accessibility and Usability of the Built Environment - Ad Hoc Group on Environments for Children with Disabilities'. More coordination within these different groups appears important and should be encouraged; for example, the CEN harmonised standard on accessible information and communication technology (ICT), also called the European standard for digital accessibility EN 301 549:2021 [36] includes some references on stationary ICT (p38) which need to be coordinated with the accessibility and usability of the built environment functional requirements set out in EN 17210 [9]. The standards however are developed by different working groups.

Outside the range of anthropometry, recent work of the International Standardisation Organization ISO/TC159 WG2 has focused on the sensory characteristics of older persons and persons with disabilities. A database has been developed for vision (font, colour, field, contrast), hearing (threshold, loudness, auditory signals, voice, TV), touch (tactile symbols), and they are working on future data for taste and smell characteristics [37]. However, this work was conducted independent of the unanswered questions regarding the anthropometry of people with disabilities, as was discussed in the previous paragraph.

ISO 9241-500 [38] defines a system as a "combination of interacting elements organized to achieve one or more stated purposes". This is clearly the case for wheelchair users, and their condition must therefore be considered using the agreed definitions of this standard, including accessibility, context of use, and intended user population when designing a system. The standard further specifies that "human-centred design, as defined in ISO 9241-210, means that all designable components of a system, product or service are fitted to the characteristics of the intended users rather than selecting and/or adapting humans to fit the system, product or service … " and that "According to ISO 9241-210:2010, 4.1., whatever the design process and allocation of responsibilities and roles adopted, a human-centred approach should follow the principles listed below: (a) the design is based upon an explicit understanding of users, tasks and environments; … ". Based on the workshop findings it has become apparent that an understanding of the anthropometric characteristics of people with disabilities is still missing, and it could be concluded that, in fact, current accessibility standards are not based on widely accepted human-centred design standards using agreed upon scientific methods and approaches as established through research and implemented for the general population.

The temporarily able-bodied population may progressively develop one or more functional limitations as they age, or they might suddenly suffer a severe functional limitation. While anthropometric data may reveal individual differences within and between populations that have different functional limitations, as populations age they may also develop balance disorders and other conditions that, both individually and collectively, progressively limit their ability to access premises or navigate and function within the built environment. Where problems are extremely complex and have many potential contributing factors, as is the case with slip resistance, for example, ergonomists must ultimately rely on a wide range of expertise to ensure that accessibility can be adequately designed. Gait biodynamic studies for example might publish traction demand data in readily utilisable slip prevention format for well-defined and more common cross sections of cohorts. While too little slip resistance is dangerous, too much slip resistance can also be problematic when designing for all, as excessive surface roughness may cause some cohorts to stumble, may challenge wheelchair users, and may also be difficult to maintain in a clean condition. In order to realise optimal outcomes, there needs to be a greater awareness of the traction that will be available throughout products' lifecycles, as well as reliably defining, in complementary terms, the traction demands of all user groups.

ISO/IEC Guide 71 [39] sets out methods for creating standards that accommodate the aged and people with disabilities. The guide refers to two approaches to addressing accessibility standards, the "accessibility goals approach" (p10) and the "human abilities and characteristics approach" (p21), and states that "the use of both approaches can result in the creation of the most appropriate set of standard-specific requirements and recommendations" (p7). It seems that the first approach, the "accessibility goals approach", was followed primarily by standardisation groups, while the second approach, a "human abilities and characteristics approach", has been neglected. Paragraph 7.4 of the guide (p26) lists physical abilities and characteristics, including body size, upper and lower body movement, strength and endurance, and voice and speech functions. While mentioning "anthropometric data values for mass and a range of static linear dimensions of people measured when standing, sitting, and with arms relaxed or outstretched" (p27), the guide makes the error of omitting the fact that such anthropometric data can normally not be measured for people with a limited physical ability because they may not be able to maintain measurement postures or they may be sitting in a wheelchair; no measurement standards exist for these scenarios. However, the guide does point out the human-system view that a range of dimensions for the smallest and largest people and the equipment they will use when interacting with the systems of which they are part, can be used to determine design requirements. In the absence of a guideline for how such measurements can be conducted, this statement must be questioned, if not rejected. Given that at least the size and shape of some people with disability can normally not be validly and reliably measured under these circumstances, as discussed above, the guide's findings that "systems that do not accommodate the size, shape or mass of some people can be very inconvenient, potentially hazardous and can completely restrict access", must be of utmost concern. In its recommendations for developing standard-specific requirements based on user accessibility needs and design considerations, the guide recommends to "set fixed parameters to accommodate the widest range of users". The scientific basis for setting such fixed parameters is yet to be defined.

5. Conclusions

Several questions arose from the workshop that need to be answered to progress the next steps towards human-centred design standards for people with disabilities. Functional limitations must be looked at individually as well as collectively. It is important to focus on functional abilities / disabilities and tasks / actions, not just on measures of single parts of the body. This approach would build on anthropometric data collected in a standardized manner, and to develop such a standard for data collection needs significant study before it can progress to useful design standards in architecture, ergonomics, or other domains. Research can build on a set of key questions, which coincide with higher level demands made in the 2011 World Report on Disability, "improve the comparability of data" and "develop appropriate tools and fill the research gaps" (p46) [40]:

1. What are the key human/device systems that should be addressed?
2. How can we quantify the greater variability in human conditions when the human is part of a system that also includes medical devices?
3. What would be a minimum or critical list of dimensions?
4. How can landmarks be defined, for every human/device system?
5. What is a reasonable definition of percentile for populations with physical and/or cognitive disability, where "Design for All" implies an exceptionally large range?
6. What is a valid percentile range in the population with physical disability as compared with the 5th – 95th percentile ergonomic design paradigm used in a general population, given that "Design for All" implies an exceptionally large or the widest reasonable range?
7. What are allowable errors, for example in accuracy and reliability, in anthropometric and functional measurements?
8. Is it worthwhile and relevant to differentiate anthropometry for different disease classes, as it may be better to focus on human/device

systems, without regard to why somebody ended up with a particular device?

9. What is an acceptable sampling strategy? This question may be addressed, again with the human/device systems. A solution probably needs equal sampling cells for each type of system, and a separate cell for people without devices who may nevertheless have limitations (older people, which in anthropometry is defined as greater than 65 years of age, for example).
10. How to apply 3D scanning methods, and interpret, quantify, and analyze the data from 3D scans? This may be very labor intensive in a population of people with disability, to process the scans afterward and separate the human from the device (where devices are used).
11. How can digital human modelling methods [41] be applied? Is it legitimate to use them in the absence of a reliable body of anthropometric data?
12. How to define functional anthropometry? Although this is not done well with standard anthropometry, the question becomes even more relevant in a population with physical and/or cognitive disabilities.

These questions lead to the following core positions and recommendations based thereon.

5.1. Recommendations

The rationale for the below recommendations is based on the arguments developed in previous paragraphs.

1) Given the global scale of the problem, that international Design for All standards are lacking a consistent standard for measuring anthropometric data, we suggest IEA, ISO and interested national/regional standardisation bodies, need to collaborate, and form a working group to commission such research.
2) We propose national/regional standardisation bodies and relevant industry associations need to provide research funds for this work.
3) We recommend research to inform a measurement standard, i.e., to collect data, and establish an online database of relevant anthropometric measurements, with open access, or at least a subscription service.
4) We urge ISO to develop a new standard with the above scope under a new ISO TC159 working group.
5) We suggest ISO and national/regional standardisation bodies to amend their existing Design for All and Accessibility standards to align with and reflect this new standard.

In addition to the physical anthropometric data mentioned above, various sensory and cognitive data are also lacking for accessibility, and collection of these data should be equally considered in the future.

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Ethical approval

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Informed consent

Not applicable.

Conflict of interest

The authors declare that they have no conflict of interest.

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