

Spring 5-1-2016

Design of Exercise Equipment for Wheelchair Users: A Case Study in Accessibility Standards

Kate Craddock Rescsanszky

University of Connecticut, kate.rescsanszky@uconn.edu

Follow this and additional works at: https://opencommons.uconn.edu/srhonors_theses

 Part of the [Biomechanics and Biotransport Commons](#), [Biomedical Devices and Instrumentation Commons](#), and the [Other Biomedical Engineering and Bioengineering Commons](#)

Recommended Citation

Craddock Rescsanszky, Kate, "Design of Exercise Equipment for Wheelchair Users: A Case Study in Accessibility Standards" (2016). *Honors Scholar Theses*. 470.

https://opencommons.uconn.edu/srhonors_theses/470

Design of Exercise Equipment for Wheelchair Users: A Case
Study in Accessibility Standards

By: Kate Craddock Rescsanszky
UCONN Biomedical Engineering May 2016

Thesis Advisor: Krystyna Gielo-Perczak, PhD
Honors Advisor: Yen Chih-Huang, PhD

Table of Contents

Title Page	1
Table of Contents	2
Abstract	3
Chapter 1: Introduction	4
Chapter 2: Standards Review	8
Chapter 3: Project Strategy: Methodology of Evaluating Standards	15
Chapter 4: Analysis and Comparison of the Alternatives	17
Chapter 5: Standards Verification: A Case Study	22
Chapter 6: Conclusions and Recommendations	30
Acknowledgments	31
References	32

Abstract

Engineers must consider a number of aspects of every project they work on. Accessibility is one aspect that presents a unique challenge. Rather than being based on absolute material parameters, accessibility is based on how people interact with technology and their built environment. Since 1990, the Americans with Disabilities Act has been the predominant standard in accessibility because of its wide reach and legal mandate. In addition to the ADA, the ASTM and the Institute for Universal Design offer helpful guidelines for designing for accessibility. However, in addition to standards, guidelines, and recommendations, it is important to consult the intended users of a project in order to best meet their needs because standards do not always take into consideration important factors, such as social context, target user demographics, and intended use environment.

As a case study in these considerations, the wheelchair roller is presented. Wheelchair rollers are a device that allow wheelchair users to exercise indoors, similar to how a treadmill allows people to walk or run indoors. This project was designed for the Hospital for Special Care under the Nielsen Grant as a part of their new wheelchair fitness room. This wheelchair roller was to be designed for a wide range of users and abilities, from people who are overweight and just beginning to exercise and become fit to those who are elite athletes looking to train indoors.

This paper will look at the ADA, ASTM, and Universal Design standards for accessibility. It will compare their strengths and weaknesses from the points of view of both engineers and the disability community, and how they should be used in engineering design. Then, the design of the wheelchair rollers will be presented in a case study; how different aspects of these standards were incorporated into the design; and how it was necessary at times to go beyond the written standards to meet the client's needs for accessibility.

Chapter 1: Introduction

Before discussing accessibility and the different standards for it, it is critical to understand a number of factors that led to the current state of accessible design. This section will offer an introduction to views about disability, history of accessibility, and the consequences of these. The aim of this introduction is to establish the role of accessibility in society and the critical importance of finding acceptable standards of accessibility.

1.1 Disability in America

Disability has long been considered to be a rigidly defined, monolithic state of existence. Traditionally in Western culture, disability has been viewed as inherently bad and for which individuals need to take responsibility. This view is now known as the individual or medical model of disability, as characterized by Mike Oliver in 1983 [1]. This name reflects the view that it was a concrete medical state existing entirely within a person. In the 1950s, along with racial and ethnic minorities, disability rights and access began to be viewed as civil rights issues [2, 3]. As a result, disabilities came to be viewed as human variations, and the limitations associated with them as externally imposed problems. This model, known as the social model of disability, is the prevailing one used today, and has a number of social, political, and structural ramifications [2, 3]. The World Health Organization (WHO) concisely sums up this definition of disability as “not just a health problem. It is a complex phenomenon, reflecting the interaction between features of a person’s body and features of the society in which he or she lives” [4].

Another authoritative definition of disability is the Americans with Disabilities Act, which is the current legal standard in accessibility in America. It defines an individual with a disability as a person who:

has a physical or mental impairment that substantially limits one or more *major life activities*, or has record of such impairment, or is regarded as having such impairment. ‘Major life

activities' include functions such as caring for oneself, performing manual tasks, walking, seeing, hearing, speaking, breathing, learning, and working [5].

This definition covers a number of different aspects of disability, but most importantly, it defines disability in terms of an impairment leading to a functional deficit. While the impairment is usually a medically defined condition, limit in functioning can be either directly caused by the medical impairment, or caused by the surrounding environment.

While these models present a way to view disability as a society, the US census shows the day to day realities of Americans with disabilities. According to the most recent census, in 2010, 19% of Americans have a disability, with more than half of those reported as severe disabilities [6]. Of those people, 30.6 million had significant ambulatory limitations, 19.9 million had difficulty lifting or grasping, 7.6 million had difficulty hearing, and 8.1 million had difficulty seeing [6]. As a consequence of these disabilities, only 41% of people of working age with disabilities were employed compared to 79% of the working age population without disabilities [6]. People with disabilities on average made nearly \$1,000 less per month and those with severe disabilities lived in persistent poverty at a rate more than twice the general population [6]. Although disability rights and access have been joined with the civil rights movement, these statistics show that equality still has not been reached for a very substantial minority of the population.

1.2 History of Accessibility

Technology itself is a form of communication. Anything built communicates the builder's values, goals, and purposes. As a whole, a built environment reflects what a society values. When the world is structured in such a way that people with physical disabilities are excluded, this communicates lack of value of their role in society. Under the medical model for disability, there was little reason to accommodate people with disabilities, since it was assumed that it was their own responsibility as well as an inherently bad thing. However, under the social model of disability and most civil rights viewpoints, the built environment is a cause of disability. When this is the prevailing worldview, accessible design

becomes necessary as a responsibility of society as a whole. While this view of disability informs the need for accessibility and the reason it is valuable, it doesn't give a practical view of what accessibility should look like. Over time, a number of standards have been developed which give guidance to engineers looking to design for accessibility. Some standards, such as the ADA, give legal mandate and specific requirements. Others, such as the principles of Universal Design, offer a set of guidelines about how an accessible design should function, without specific and concrete instructions. Still others, such as some ASTM standards, try to quantify and simplify the principles set forth in both the ADA and universal design into easy to follow guidelines.

1.3 Consequences of Accessibility

The follow-up report “Sharing the Dream: Is the ADA Accommodating All?” by the U.S. Commission on Civil Rights states that “one of the areas of improvements were access to building, greater inclusion of people with disabilities in the community, increased public sensitivity and awareness, public respect and acceptance” [7]. “Inclusion”, “sensitivity”, and “acceptance” cannot be legislated or forced, so it is obvious that they come as a secondary result of the changes made by increased accessibility in public places due to the passage of civil rights legislation. As shown before, the ADA is the very minimum of accessibility, meeting only the explicit physical needs for access rather than the broader social perception and ways of determining best use. If such a big change is seen from an inherently limited set of guidelines and rules, how much more acceptance and social change could occur from more robust and complete guidelines for accessibility?

In addition to the explicit goals of more physical access and greater social acceptance, more universal accessibility can also create a self-perpetuating cycle that will help people with disabilities to live richer lives as fully integrated members of society. The client for the senior design project mentioned that fitness for people with disabilities is a self-perpetuating negative cycle: without adequate fitness equipment, people fail to maintain fitness. As they get less fit, they get out less to interact with people and thus get less exercise. They may reach a point where they are unable to use current exercise equipment

due to their size. At this point, they are locked into a cycle of lack of fitness and lack of social and community involvement, both of which harm them as an individual and serve to cause each other. Similarly, increased access can start a cycle as well. As people with disabilities are better able to access the community with everyone else, other people will meet individuals with disabilities and see them as regular people with the same rights and needs as themselves. And as people with disabilities become more familiar and more involved in society, people will demand greater access and equality, continuing the cycle. In this way, the built environment serves the elimination of the difficulty with disability not only in removing physical barriers but also remedying social inequality and misperceptions.

This type of social power is rarely discussed among engineers, but as the gatekeepers to access to medical technology, biomedical engineers hold enormous power for social change. For this reason, it is absolutely critical that proper standards for accessibility are discussed. Such standards are more than simply a best practice or a convenience, but a matter of civil rights and equality. This is of utmost importance for engineers to understand and apply.

Chapter 2: Standards Review

This section will present the three predominant standards in accessibility: The Americans with Disabilities Act, The Principles of Universal Design, and the ASTM Standards related to accessibility. These standards have a variety of roles and purposes, which will be discussed as well.

2.1 Americans with Disabilities Act

The Americans with Disabilities Act (ADA) was first enacted in 1990 with the intention to “prohibit discrimination and ensure equal opportunity for persons with disabilities in employment, State and local government services, public accommodations, commercial facilities, and transportation” [5]. Substantial updates were made in 2010, to include the “ADA Standards for Accessible Design” as well as other specific regulations [5]. Prior to the ADA, only federally-funded entities were required to be accessibly designed under Section 504 of the Rehabilitation Act of 1973, which led to large numbers of public spaces being inaccessible to people with mobility limitations [8].

The ADA currently sets the minimum standards for what can be considered accessible as well as the legal penalties for public places that do not meet these standards. For these reasons, it is probably the best known and most widely used standard of accessibility in America. A simple web search of “accessibility guidelines” turns up information about the ADA exclusively for the first page. While the ADA is extremely extensive in scope and content, this paper will look at an overview of the applications and then certain standards as they apply to the specific case study presented.

The ADA covers a broad range of disabilities and situations. The definition of disability established under the ADA covers anyone who “has a physical or mental impairment that substantially limits one or more *major life activities*, or has record of such impairment, or is regarded as having such impairment,” as mentioned above [5]. This covers a very large number of people and different functional limitations.

Title III is the section of the ADA that specifically lays out standards for accessibility, when they are required, and what the consequences are for not meeting the. The ADA covers a wide range of circumstances requiring accommodation or modification, but for the sake of this paper, discussion will

primary focus on physical access rather than delivery of services. Delivery of services refers to the way that certain businesses, such as deliveries, are run to ensure access to all people. This falls less in the realm of engineering, so it will not be discussed here. Physical access will refer not just to the construction of buildings, but also to how spaces are laid out to ensure accessibility, and what equipment and technology is to be located in buildings. These are often relevant and important considerations for engineers.

Where it Applies

The listed types buildings covered by the ADA are “Public accommodations (i.e./ private entities that own, operate, lease, or lease to places of public accommodation), commercial facilities, and private entities that offer certain examinations and courses related to educational and occupational certification” [5]. This includes most buildings that are open to the public. Explicitly not included in Title III are religious buildings, private clubs, and state and local government buildings, although the latter are under different laws regarding accessibility. Accessibility for facilities refers not only to the structural layout of the building, but also to how the building is set up and what equipment and technology is used within the buildings. Because it includes equipment and technology to be used, ADA compliance is an important concern for all engineers, not just those who are structurally designing the buildings, but also those who are designing any piece of equipment that people might interact with in the covered public places.

Facilities that fall under the category of public accommodations may be granted exceptions for a number of reasons. If they can prove that accessibility would “fundamentally alter” operation of the building, if it is not “easily accomplishable and able to be carried out without much difficulty or expense,” or if it is “structurally impracticable” [5]. In addition, buildings with historical significance, residential buildings, and buildings under a specified size are granted exemptions. However, these exemptions are less common, and accessibility is always the preferred design.

Barrier Removal

Any building open for public service constructed before the ADA was passed was given a period of time to be retrofitted to the standards or else they would be penalized. At the time, this often required extensive modifications. This included “installing ramps, widening doorways, [and] installing grab bars in toilet stalls” [5]. Businesses are granted a tax credit up to \$15,000 for barrier removal [7]. At this point in time, most facilities should have already passed the phase of barrier removal and the standards for new construction or alterations are typically most relevant.

New Construction

Alterations and new construction approved after the passage of the ADA fall under “new construction” and the associated rules. The standards for new construction are more frequently updated and are regulated by the Architectural and Transportation Barriers Compliance Board, an independent Federal Agency which has been created to regulate and oversee accessibility guidelines and their changes over time. These guidelines lay out precise standards such as the maximum ramp slope, minimum door width, definitions of accessible restrooms, minimum width between fixed structures, and more. These are the standards that engineers have to take into account most often for design projects, as shown in the case study. Exceptions to these rules are much rarer, as the buildings will not have built in structural impracticability. Exemptions are only considered “in those rare circumstances when the unique characteristics of the terrain prevent the incorporation of accessibility features (e.g., marshland that requires construction on stilts)” [5]. Because these standards are the strictest and most explicit, they are most often the ones which must be taken into account by engineers designing something for public use.

Rules for when some, but not all, must be accessible

An interesting case under Title III of the ADA is situations in which some, but not all of a public building must be accessible. There are specific guidelines for all different kinds of facilities, but the percentage that must be accessible varies greatly depending on the type of accommodation. For example, 50% of public entrances must be accessible, every public bathroom must have one accessible stall per six non-accessible stalls, buildings without a sprinkler system must contain an area of refuge, and all

restaurants and libraries must have five percent but no less than one of their tables be accessible [5]. In these cases, separate designs are needed for the accessible and non-accessible parts, and the designer must take into consideration that the overall structure is compliant with the accessibility guidelines.

Enforcement

Failure to comply with the ADA without being granted a valid exemption counts as discrimination and is persecuted as such under other Department of Justice procedures. Complaints of noncompliance can be lodged either by private parties or can be filed with the Attorney General. Private cases are not allowed to result in monetary damages being paid, but suits by the Attorney General may [5]. As a discrimination suit, noncompliance has significant consequences for engineers who do not abide by the guidelines in the ADA.

2.2 Principles of Universal Design

As accessible design came into focus with the civil rights discussions of the 1950s-1970s, some groups focused on the nature of accessibility, rather than quantifying it into law. One of the first people to write about this was architect Michael Bednar, who believed that “everyone's functional capacity is enhanced when environmental barriers are removed” [3]. The formation of the disability rights movement in the 1980s gave the ideas of Bednar and others backing and social force. The term “Universal Design” was coined during this period by American Architect Ron Mace, who himself was a wheelchair and ventilator user [3]. From this school of thought came the Principles of Universal Design. The Center for Universal Design (CUD) defines it as “the design of products and environments to be usable by all people, to the greatest extent possible, without adaptation or specialized design” [9]. Under this definition, the CUD lays out seven principles with sub-guidelines to guide accessible design. While these standards have no legal or technical bearing, they do influence designers and offer guidance on how to make something accessible to as many people as possible.

Because the Principles of Universal Design are relatively short and already concisely worded, they are listed in their entirety here, as given by the Center for Universal Design, under the College of Design at NC State University in Raleigh, NC:

- “1. Equitable Use: The design is useful and marketable to people with diverse abilities
 - a. Provide the same means of use for all users: identical whenever possible; equivalent when not
 - b. Avoid segregating or stigmatizing any users
 - c. Make provisions for privacy, security, and safety equally available to all users
 - d. Make the design appealing to all users
2. Flexibility in Use: The design accommodates a wide range of individual preferences and abilities
 - a. Provide choice in methods of use
 - b. Accommodate right or left handed access and use
 - c. Facilitate the user’s accuracy and precision
 - d. Provide adaptability to the user’s pace
3. Simple and Intuitive Use: Use of the design is easy to understand, regardless of the user’s experience, knowledge, language skills, or current concentration level
 - a. Eliminate unnecessary complexity
 - b. Be consistent with user expectations and intuition
 - c. Accommodate a wide range of literacy and language skills
 - d. Arrange information consistent with its importance
 - e. Provide effective prompting and feedback during and after task completion
4. Perceptible Information: The design communicates necessary information effectively to the user, regardless of ambient conditions or the user’s sensory abilities.
 - a. Use different modes (pictorial, verbal, tactile) for redundant presentation of essential information
 - b. Maximize “legibility” of essential information

- c. Differentiate elements in ways that can be described (i.e., make it easy to give instructions or directions)
 - d. Provide compatibility with a variety of techniques or devices used by people with sensory limitations
5. Tolerance for Error: The design minimizes hazards and the adverse consequences of accidental or unintended actions
- a. Arrange elements to minimize hazards and errors: most used elements, most accessible; hazardous elements eliminated, isolated, or shielded
 - b. Provide warnings of hazards and errors
 - c. Provide fail safe features
 - d. Discourage unconscious action in tasks that require vigilance
6. Low Physical Effort: The design can be used efficiently and comfortably and with a minimum of fatigue
- a. Allow user to maintain a neutral body position
 - b. Use reasonable operating forces
 - c. Minimize repetitive actions
 - d. Minimize sustained physical effort
7. Size and Space for Approach and Use: Appropriate size and space is provided for approach, reach, manipulation, and use regardless of user's body size, posture, or mobility
- a. Provide a clear line of sight to important elements for a seated or standing user
 - b. Make reach to all components comfortable for any seated or standing user
 - c. Accommodate variations in hand and grip size
 - d. Provide adequate space for the use of assistive devices or personal assistance" [9].

2.3 ASTM Accessibility Standards

The American Society for Testing and Materials (ASTM) is a world leader in the creation and implementation of voluntary standards. Currently, there are over 12,000 ASTM standards that are used to improve safety and quality in a wide range of industries [10]. These standards are entirely voluntary in their compliance, however, the standards are often referenced in laws, or may reflect standards from specific laws, such as the ADA.

A search for accessibility in the ASTM standards brings up 242 individual standards and 549 related publications. Each entry represents a very specific aspect of accessibility such as “Determination of Accessibility of Surface Systems Under and Around Playground Equipment” (ASTM F1951-14) or “Accessibility Facility Assessments of Private Non-transient Housing” (WK50995). It would be extensive, and unnecessary, to summarize all of the standards related to accessibility and people with disabilities here. For the sake of the case study presented later, this paper will focus on “Standard Specification for Universal Design of Fitness Equipment for Inclusive Use by Persons with Functional Limitations or Impairments," which is standard F3021 – 15.

This standard covers a number of specific aspects of exercise equipment that need to be considered in design. It includes a wide range of topics which attempt to codify a combination of ADA requirements and universal design principles. It specifies preferred directions of approach, minimum and maximum sizes of parts of devices, and types of surfaces to be preferred. It also specifies what types of labeling will be most visible, most easily understood, and most likely to lead to correct use. Another important aspect of it is what types of motions are acceptable (i.e./ not using both hands simultaneously) and how much force can reasonably be expected from the user in certain positions.

Chapter 3: Strategy: Methodology of Evaluating Standards

When deciding which standards are relevant and at which times, there are a number of factors that must be considered.

The first factor to consider is the relevance. Some standards may be useful in certain context, but meaningless in others. For example, standards related to door width wouldn't apply for considerations for a small handheld device. It is important to be aware of a wide variety of standards and to be able to choose and use the most relevant one. For the purposes of this paper and the included case study, standards will be considered relevant if they pertain to how people who use wheelchairs exercise or are able to access exercise equipment. A few other situations will be included for the sake of discussion, but this will be used as the primary relevant situation.

The next factor to consider in evaluating accessibility standards is the enforceability of the standards. There are a number of ways in which standards might need to be enforced. The most obvious is through legislation, such as with the Americans with Disabilities Act. However, there are a number of other ways which standards might be "enforced". Some standards are used to award a certification, such as the LEED certification issued to buildings that meet certain qualifications of environmental friendliness. Other standards are voluntary, but widely accepted among professionals, such as ASTM or ISO criteria.

If a standard is to be enforced, there must also be some way to assess whether it is met or not in a certain design. For this reason, standards of accessibility should be measurable and specific. Measurability allows a design to either "pass" or "fail" meeting the standard. In order to make a judgement that will be consistent across all cases, the measurement should be objective, such as physically measuring some aspect of the design. This allows assessment of whether a product meets the standard to be consistent and replicable. Consistency ensures that the same standard is being applied to all designs, meaning that everything designated "accessible" truly does meet the same minimum level of accessibility. This is critical for establishing a standard, because without consistency the standard has little value to the public or to designers. Replicability is also important to ensure that the same results

occur regardless of who is assessing the accessibility of the design. A truly accessible design must be considered accessible not only by the designer, but also by people with disabilities and any outside regulators. For this reason, standards that are measurable must give explicit instructions as to what is considered accessible or not. Explicit definitions will allow all parties to make a fair and accurate assessment of the accessibility of a design. The standards should also be specific as to where they apply. Some standards will be good in one case, but not in others. However, if they are to be applied meaningfully, it should be specified within the standard where they are meant to apply, so designs won't unnecessarily be designated as "failure" when the standards are not meant for them in the first place.

Finally, the standards themselves should be accessible to the intended audience. For accessibility design standards, the intended audience would of course be engineers. A good set of standards should be written in language that engineers would be able to make meaningful use of. Technical language may be considered accessible to this group, but legal jargon likely would not. In addition, it should be something that is brought into the conscious consideration of people who otherwise may not be thinking of designing for people with disabilities. It shouldn't be tucked away somewhere that it can only be found by explicitly searching for designing for people with disabilities. It should be considered part of an overall best practice approach. However, the stronger the enforcement of the standards, the more likely that it will be in the awareness of all engineers.

Chapter 4: Analysis and Comparison of Standards

Americans with Disabilities Act

Of all the relevant standards, the ADA has the most significance in terms of absolute necessity to engineers. Since failure to comply with it is prosecutable as discrimination, it is absolutely critical that designers are aware of its included standards and meet them with every project. Because of this, everything that is designed in, or for use in America meets these standards at a very minimum. The ADA is also the most quantifiable of the standards. A design either meets ADA standards or does not meet ADA standards, and can be labeled and evaluated as such, which is a benefit in making comparisons and other decisions between designs or products.

The ADA also covers a wide range of issues related to accessibility, from physical spaces to telecommunications. Because it covers so many different areas of accessibility, it has a wide reach and affects many different industries. In 2000, in a poll of people with Cerebral Palsy, 63% indicated that they felt their access to public spaces had improved since the ADA was passed [7].

While the ADA lays out very explicit guidelines to enumerate accessibility, sometimes it fails to take into account social aspects to accessibility. As will be discussed in depth under universal design, sometimes accessibility not only takes into account literal physical access to a space or device, but how that access is achieved and how the individual gaining access is perceived by others. While the ADA may grant individuals access, sometimes there is more to accessibility than just access, which is often missed by spaces or devices that are fully ADA-compliant.

Another potential problem with the ADA is the size and type of language. The full standards take up 279 pages and are updated frequently, so they require frequent review [11]. In addition, it is written in legal language, which may not be as familiar to the engineers and other designers who are actually designing everything that needs to comply with the ADA.

Universal Design

Universal design offers a very high standard for accessibility in design. It addresses all aspects of design as well as all different ways people might need to be accommodated and the way that people are perceived while using a device. For these reasons, it represents a very good ideal goal, although it may be difficult or impossible to simultaneously satisfy all of the requirements for all possible users. This leads to a standard that engineers can be continuously striving to meet and improve upon, but may never actually meet.

As previously mentioned, there are many situations in which a design could be considered accessible and ADA-compliant, but may fail to account for the social problems associated with disability, which under prevailing viewpoints make up the largest problem associated with disability. A very common example of this is buildings that require people with wheelchairs to enter from the back. While this technically meets the code under the ADA, this solution definitely does not meet universal design standards. It is reminiscent of racial segregation and can be frustrating and stigmatizing to people who have to use the entrance. While obviously there are legitimate reasons as to why this design may be necessary (unalterable historic buildings, etc), it should be prevented as often as possible if people are truly to receive equal access. The first two principles of universal design specifically address this flaw with the traditional standards. “Equitable use” aims to ensure that people are able to access something in the same way if at all possible, and in an equivalent, non-stigmatizing, and appealing way if not possible. Similarly, “flexibility in use” also aims to ensure that the majority of people are able to access something by having multiple ways of doing so. An example of this is stairs vs. ramps. Both walking and non-walking people are able to use ramps, but only walking people can use stairs. So ramps would be an example of something with flexible use, while stairs would be less flexible. However, this again creates issues, as the ramp may make it more difficult for a blind person who uses a cane to find their way around. There is rarely a perfect solution, but there is often a better solution. This is why careful training and consideration by the designing engineer is important in order to make sure that as many people as possible have access to a certain design.

Even the creator of the term “universal design” recognized that it represents an unattainable ideal. The word “universal” implies that it is possible to find a solution that will be functional and accessible for everyone, but “No matter how committed the designer and how attentive to anticipating all users, there would always be a small number of people for whom an individual design just wouldn't work” [3]. For example, curbs are obviously inaccessible to a wheelchair user, but blind people who use canes may find smooth surfaces impossible to navigate. Any solution that benefits one of these groups makes navigation more difficult for the other: obviously no solution can benefit all people at all times and in all situations. The concepts of universal design encourage designers to try to consider this unattainable ideal in order to come as close to being universally accessible as possible, but inevitably fall short of true universality.

The standards of universal design have little use for legal mandate or technical certification. As mentioned above, no piece of technology is truly perfectly universal, so there must be some compromises made. Thus, the concepts given are meant more to guide the design process rather than evaluate a finished project. For this reason, it would be difficult to codify them into law or to create a certification or approval based on the standards. To do this, one would have to ask questions like “is this simple and intuitive to use?” or “did the designer consider enough different ways to access this?”. While these are useful questions for the designer to ask themselves, they would be difficult to enforce or establish by an outside regulatory body. Although universal design offers much important guidance on design considerations, it is unlikely that it could provide a meaningful stand-alone standard for accessibility.

The principles of universal design are also difficult to quantify and therefore assess and enforce. Guidelines such as “Avoid segregating or stigmatizing users” or “Eliminate unnecessary complexity” are difficult to put into concrete, fully objective terms to measure and compare between designs. To truly understand if a design is effective in meeting these principles, it may be necessary to observe a variety of users with the product for a period of time, or to talk with the actual user group. While all of the principles may have been considered by engineers during the design process, it is difficult to call something “universally designed” because someone else might assess the design’s effectiveness at meeting the criteria differently than the original creator. While there have been some successful attempts

to quantify and standardize parts of the universal design criteria, as will be shown in the section on the ASTM guidelines, overall universal design better serves as a guiding process rather than an absolute set of standards.

At present, universal design principles are extremely popular in educational theory and telecommunications design [3]. However, they have yet to gain popularity in a number of other areas, such as the broader engineering field. The case study presented later will show a number of ways that these principles can be taken into consideration in a traditional engineering design project that is specifically designed for people with disabilities. However, universal design would also benefit projects not specifically designed for people with disabilities as well.

ASTM

The ASTM tries to incorporate a variety of elements from both traditional accessible design and universal design principles into some of their standards in a way that is familiar and easy to use by designers and those familiar with these types of standards. It points out a number of different aspects that might be unfamiliar to some designers from this perspective. For example, a designer focusing on designing for people with mobility limitations might forget considerations for people with sight limitations or vice versa. Or in the more common case, a designer may fail to take into account various limitations and design for the typical person. These guidelines point out and enumerate exactly what should be done in order to make as many things accessible as possible. Often, engineers are taught to design for the average user, which is most often proportioned as an able-bodied male. Recommendations such as these help engineers to learn to design for people that are far away from the mean in ability, size, or way of performing different actions. Having these explicit guidelines can be particularly helpful for engineers with no training in universal design or experience with people with disabilities.

The ASTM standards themselves are not accessible to everyone. The full standards are very expensive and engineers without substantial backing or ties to an academic institution may not be able to access them as needed. As such, a designer who is not already thinking inclusively is unlikely to specifically seek out the standards pertaining to people with disabilities. While effective if used, this

mode of distribution makes them less likely to be used by the people who really ought to be using them, and only actually used by the people who are likely to already be making those considerations.

Attempts to quantify the principles of universal design run the risk of making the designer feel that they have considered all possible users if they have in fact met a specific list of suggestions. This runs contrary to the nature of universal design, which encourages the designer to think about how their final product will be used and to account for all possible uses and variations in use. While helpful for engineers who are unable to observe their product in use, the ASTM universal design guidelines are not a complete replacement for thoughtful consideration about the people who will be using the designed product.

However, the nature of the ADA encourages an attitude of explicit compliance, rather than thoughtful consideration of all of factors affecting access and use of a product. The universal design standards present a near opposite. They are helpful guidelines for thoughtful consideration and present a number of important aspects of design, but they give little explicit guidance. In addition, they are difficult to quantify and thus also difficult enforce or certify in any meaningful way. The ASTM standards cover a number of different issues, including accessibility and universal design. However, attempts to quantify universal design may run contrary to the thoughtful nature of the principles. In addition, the standards are difficult to obtain, especially for people who are not already explicitly searching for that kind of guidance.

Chapter 5: Standard Verification: A Case Study

In order to test out the feasibility of these recommendations, a case study of a senior design project for people with disabilities is presented. This project was designed with all of the above mentioned standards in mind and will be used to illustrate some applications of them.

Background

Wheelchair rollers are a device that allow wheelchair users to exercise indoors, similar to how a treadmill allows people to walk or run indoors, although there is much more variation in the design. Typically, wheelchair rollers are designed like industrial rollers, although some higher end models feature a belt like a treadmill. This wheelchair roller design project was to be designed for a wide range of users and abilities, from people who are overweight and just beginning to exercise and become fit to those who are elite athletes looking to train indoors. As such, considerations into universal design and were traditional standards of accessibility were particularly important for this project in order to ensure that this device is in fact accessible to the wheelchair users.

While wheelchair rollers are not a new idea, there were a number of complaints about what is currently on the market. One major complaint is cost. The least expensive model on the market is \$850, and this model is rather unsafe and not large enough for many people. Other models range from \$850 to \$15,000. In addition, the client reported that several models rock during use, making the user feel unsafe and hesitant to exercise. Since sports chairs have cambered wheels and chairs for people who are overweight or obese are significantly wider, these groups of people may need rollers that can be used with a chair up to 40" wide. They should also be capable of supporting a person weighing 350 lb, plus the weight of the chair. The majority of existing models also do not come in large enough widths or weight limits to accommodate this wide range of users. Often rollers are designed to be used with a specific type of wheelchair, such as a basketball chair or an everyday chair, but it is very costly to buy separate rollers for all of the different types of chairs clients may use, for a gym or hospital to be used by many people. Finally, many online reviews of rollers often complained that they couldn't be used without assistance,

which is particularly important for rehabilitation and community programs that are looking to promote independence.

Client and Project

This project was presented by Janet Connolly, the Sports and Community Programs Manager at the Hospital for Special Care in New Britain, Connecticut. The Hospital for Special Care is a rehabilitation hospital that has a number of programs that reach out to people with disabilities in the community, including wheelchair basketball, track, and soccer teams as well as open fitness and recreation hours. They are currently in the process of building an adaptive fitness room where the athletes from the teams as well as community members and hospital patients who are looking to get fit can come and use accessible exercise equipment. Since it will be used for such a wide range of abilities, from people that are just recovering from surgery to elite athletes, this project posed a number of unique design and accessibility considerations.

While there are currently several models of rollers on the market, our client as well as several wheelchair users felt that the models on the market are inadequate for a number of reasons, including stability, size, cost, and versatility. For this reason, this project was proposed and was added into the funding proposal for the fitness room at the Hospital for Special Care. The fitness room and this project were funded by a grant from the Nielsen Foundation, which is “dedicated to research and programs to improve the quality of life for people living with spinal cord injury” [12].

Client Concerns

This project started with the client’s concerns. The client presented a number of specifications that had to be met at a very minimum:

- In order to accommodate overweight users who are using larger chairs as well as athletes in cambered sports chairs, the rollers must have a minimum width of 40” of usable space.
- On occasion, for short periods of time, the user may be going as high as 20 mph.
- To be competitive with current models, the price must be under \$800.

- The design must provide a feeling of stability and not rock excessively during use.
- More generally, the user should be in a safe and relatively natural position during use.
- The weight limit must accommodate people around 350 lb, using 25 lb chairs.
- Ideally, most users should be able to use the device without assistance.
- However, it must be possible to use the device with assistance, for those who would like to exercise but may require assistance for many daily activities.
- The rollers will be used for a variable amount of time daily, but could be used for several hours some days, depending on who is using it.
- The client explicitly stated that portability and space were not significant constraints, as the device was intended to be stationary and there was significant space allotted for it within the fitness room.

Considerations of Standards and Client Concerns

Various methods to mount the device were considered, but a ramp was ultimately chosen because it was the method most familiar to wheelchair users since they use ramps in a variety of daily circumstances. Other considerations for how to mount the device included a hand controlled scissor jack and an electronic jack. However, the ramp was chosen, in large part because it was the most familiar and easy to use, both for the roller user and the person performing maintenance. This is in line with “simple and intuitive use” of the universal design principles as well as the ADA and ASTM guidelines.

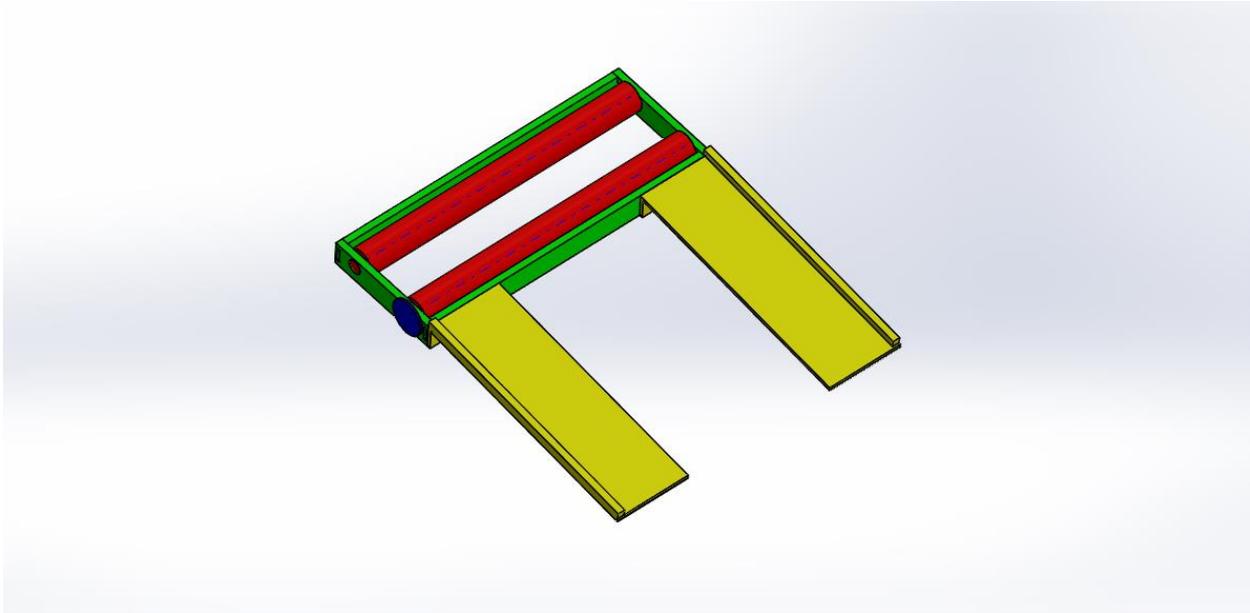


Image 1: Early design with separate ramps for each wheel

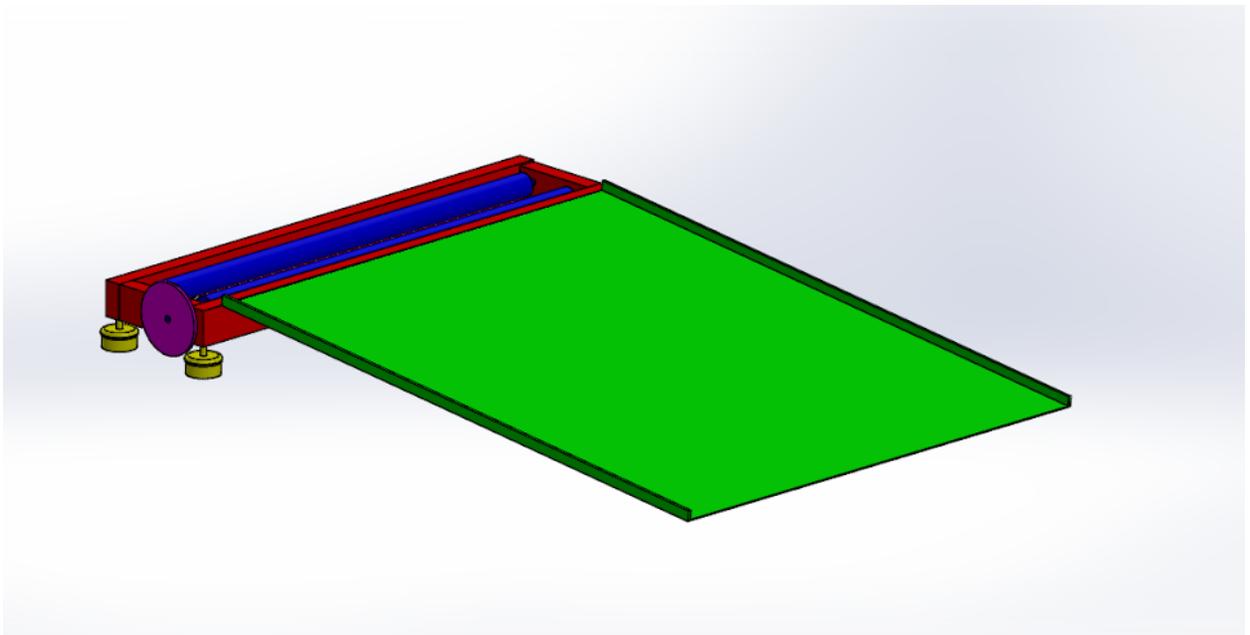


Image 2: Final design with continuous ramp

The initial design had ramps with separate tracks for each wheel as shown in Image 1, but Janet, who is familiar with the principles of universal design, suggested that it be one solid piece in order to increase the tolerance for error and allow for flexibility in use, also key principles of universal design. This would allow for users to mount the ramp safely even if they are not perfectly centered. This was the

design that we settled on, as shown in Image 2. It also allows for a variety of types of wheelchairs, including three wheel designs and ones with very narrow front wheels. Once the ramp was chosen, it was necessary to design it in a way that met the standards set for ramps under the ADA. For a ramp under 6 feet of run, this means that the slope should be between 1:10 and 1:12 [13].

Additional considerations of standards of universal design were built into the client's initial requests. The entire premise of the project was based on Equitable Use, particularly in that users of all different ability, fitness, and weight levels would be able to use the same equipment in the same way, without having separate rollers for people with different ability levels.

Since the ASTM standards were written for exercise equipment that would be used for both people with and without disabilities, many of the considerations were unnecessary for a product intended for use only by wheelchair users. However, some of the considerations were important such as the preference for front/back entry over side entry, as well as the consideration that anything that needed to be actuated by hand not require excessive force. In order to reduce the force and effort needed to release the brake, as well as to allow options for how to use it, a small fabric handle was added to the brake to allow the user to pull the handle from different positions, as shown in Image 3. This is in line with both the ASTM standards and universal design standards, as it minimizes the force needed to actuate the brake manually as well as allowing it to be done from a variety of positions and hand grips.



Image 3: Closeup of brake with fabric handle

The client, Janet Connolly, was familiar with universal design and made a number of recommendations according to that and her experience working with the user group. She suggested that the user be in as natural of a position as possible to encourage “simple and intuitive use”. She advised that for wheelchair users, being on a slight incline with the wheels tilted forward is an insecure and unstable position. The small flat area before the ramp was added so that the front wheels would be level with the back wheels to make the user feel more secure.

A SolidWorks drawing of the final project is shown in Image 2. The final product is shown, with a wheelchair, in Image 4 and by itself in Image 5. The rollers are made out of steel, which is able to resist deflection under the large loads needed, particularly at the length needed to accommodate the larger wheelchairs. This makes the system very heavy, but since movability wasn’t a concern for the client, this was an acceptable tradeoff to make the design more accessible to all. The ramp was designed to both be

simple and intuitive for wheelchair users, as well as to be safe and to not require excessive force to mount the device.



Image 4: Completed Product with Wheelchair



Image 5: Completed Product without Wheelchair

Chapter 6: Conclusions and Recommendations

The intro to this paper listed just a short excerpt of the World Health Organization's definition of disability. Here is a more complete excerpt, showing the importance of accessibility:

“Disability is thus not just a health problem. It is a complex phenomenon, reflecting the interaction between features of a person's body and features of the society in which he or she lives. Overcoming the difficulties faced by people with disabilities requires interventions to remove environmental and social barriers” [4].

This complete definition shows that disability is not just a feature of an individual, but rather an interaction between the features of that individual and their built environment. It highlights the importance of accessibility as a way to overcome difficulty. If this definition is true, nearly all of the parts of disability which are difficult or undesirable can be eliminated by introducing thorough and appropriate accessibility. Without the built in social inaccessibility, disability is just a feature of a person's body rather than an inherent difficulty and limitation. This gives designers and engineers enormous power in correcting some of the civil rights issues still faced today by people with disabilities.

It is rare that engineers have this kind of opportunity to enact social change. However, it is obviously a large task to reach this level of equality through accessibility. First, opinions on disability must overwhelmingly shift away from the individual model, in which disability is inherently difficult based on a physical impairment and the individual must compensate for it. Under this view, nobody except the individual has any place accommodating for the disability. Rather, under the social model of disability, where disability and its accompanying difficulty result from the combination of physical limitation and a barrier-laden environment, society is given the responsibility and engineers are given the ability to do something to ameliorate the problems associated with disability. While this view is widely accepted in the civil rights and disability advocacy communities, engineers do not often consider it. Second, the view of accessibility must change. It is often thought to be something that is just to be considered when designing buildings, and even then only to the minimum requirement. However, if society is to be

fully integrated, it is necessary that more engineers and designers consider the full extent of accessibility across a wide range of products for a wide range of abilities. A very useful tool for this is the principles of universal design. Additional education in the principles of universal design, as well as models of disability, would greatly benefit upcoming engineers who will be designing for a diverse population.

Mike Oliver, one of the foremost disability rights scholars, wrote “Models are ways of translating ideas into practice and the idea underpinning the individual model was that of personal tragedy, while the idea underpinning the social model was that of externally imposed restriction” [1]. As the shift, hopefully, continues towards the social model of disability, the ideas will be translated into practice, which will be translated into engineered solutions for a more inclusive and accessible society.

Acknowledgements

I would like to acknowledge my senior design group members, Alexis Henry and Danielle Soucie, as well as our faculty mentor, Krystyna Gielo-Perczak; our graduate assistants, Anna Roto and Shaniel Bown; and Janet Connolly and Carlos Quiles from the Hospital for Special Care. Funding for the senior design project featured as a case study is provided by the Nielsen Foundation.

References

- [1] M. Oliver, "The Individual and Social Models of Disability," *Reader in Dis. Studies*, 1990.
- [2] T. Shakespeare, "The social model of disability," in *The Disability Studies Reader*, L. J. Davis, Ed. 2013, .
- [3] Institute for Human Centered Design, "History of Universal Design," 2015, .
- [4] (2016). *Disabilities*. Available: <http://www.who.int/topics/disabilities/en/>.
- [5] (). *Title III Highlights* [<http://www.ada.gov/t3highlight.htm>].
- [6] (July 25, 2012). *Nearly 1 in 5 People Have a Disability in the U.S., Census Bureau Reports*.
- [7] U.S. Commission on Civil Rights, "Chapter 2: The effects of the ADA," in *Sharing the Dream: Is the ADA Accommodating all?* Anonymous 2000, .
- [8] (September 15, 2010). *Information and Technical Assistance on the Americans with Disabilities Act*. Available: http://www.ada.gov/2010ADASTandards_index.htm.
- [9] J. Woodard, "The principles of universal design," NC State University: College of Design, Raleigh, NC, September 2006.
- [10] ASTM, "Detailed Overview," 2016.
- [11] Department of Justice, "2010 ADA Standards for Accessible Design," September 15, 2010, .
- [12] Anonymous "Craig H. Nielsen Foundation: Home," 2015.
- [13] U.S. Department of Justice, "Guidance on the 2010 ADA Standards for Accessible Design," September 15, 2010, .