UTILIZING CAPABILITY DATA TO INCREASE DESIGN UNIVERSALITY

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by
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ABSTRACT

This study explores the ranges of humans’ physical capabilities and how these ranges can be considered while creating designs, including designs that are universal. Universal design is a design technique used to minimize the capability requirements of products without hindering functionality. It revolves around creating products that everyone can use, regardless of any disabilities. Designers frequently focus on creating a design for a specific target market that does not include users with disabilities; however, recent studies have shown that creating designs for both people with and without disabilities is beneficial for ethical and financial reasons, and often results in an improved design for all. Therefore, human capability data can be used to create universal designs appropriate for the vast ranges of capabilities that exist in people with and without disabilities. The proposed methodology specifies how capability data can be used to determine requirements for typical, accessible, and universal design types, which are distinguished by the capabilities of the populations for which they are each designed. A grip strength example is presented that demonstrates how these capability requirements are calculated. Furthermore, several defining aspects of universal design are identified, and a modification to the Seven Principles of Universal Design is proposed to include these defining aspects. The primary contributions of this research are: (1) specific methods for calculating the capability levels necessary for typical, accessible, and universal designs; (2) an evaluation of the differences between universal designs and accessible designs; and (3) a modification to the Seven Principles of Universal Design that will help to prevent designers from mistakenly creating accessible designs while intending to create universal designs.
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CHAPTER 1

INTRODUCTION

The objective of this thesis research is to develop and present a detailed approach for calculating capability requirements for typical, accessible, and universal design types. This approach analyzes the capabilities that exist within a target population and emphasizes specific capabilities depending on the type of design being created. The proposed calculations are necessary because designers currently lack a quantitative methodology for establishing capability requirements based on the proposed universality of a design. By utilizing capability data to establish design requirements, designers are able to achieve desired accommodation levels without wasting money on “excessive” accommodation. In particular, designers will be able to create universal designs for people with and without disabilities by focusing on the ranges of capabilities that exist among those people.

Universal design is a design technique aimed at creating products that are usable by everyone. To achieve this goal, the capability required to use a universal design is determined such that it does not discriminate against individuals with less ability. Additionally, the capability requirements of a universal design are established in a way that does not limit the design’s functionality.

The exact origins of the universal design movement are somewhat debated. Preiser (2008) claims that universal design originated after World War II, when universities were modified so that people with disabilities from the war could attend them. However, Bremer et al. (2002) state that universal design came from architects who did not want to force users to adapt to designs that were not suited for them. Story et al. (1998) maintain that universal design derived from the barrier-free movement of the 1950s, when it was
determined that designs created specifically for people with disabilities were often more expensive and unattractive than other designs. Regardless of its origins, universal design has seen significant advancements over the last 20 years (Dong, 2007).

There are many reasons why universal designs have seen a recent increase in popularity; among these reasons is increased lifespan (Mace et al., 1996). The average life expectancy for U.S. men was 58 years in 1930, compared with 74 years in 2001. A similar comparison among women reveals that the average life expectancy for U.S. women increased from 62 years in 1930 to 80 years in 2001 (Sonnega, 2006). The Federal Interagency on Aging Related Statistics predicts that 20% of the U.S. population will be over the age of 65 by 2030, and the United Nations estimates that 22% of the world’s population will be over the age of 60 by 2050 (Ehrenman, 2005). Unfortunately, living longer often means living with a disability, since disabilities occur most often in the elderly population. It is estimated that 46% of the individuals over the age of 65 are living with some form of disability (Mace et al., 1996). These individuals are able to take advantage of and appreciate universal designs since universal designs do not discriminate against their limited capabilities.

There are several specific examples that are frequently cited when trying to describe the general concept of universal design. One the most widely cited universal design success stories involves the OXO Good Grips product line, which was first released in April 1990. Sam Farber created this product line after watching his wife struggle to use common kitchenware because of her arthritis. Farber’s intention was to shift the design focus from using cheap and easy manufacturing techniques to creating kitchen products that were easier for elderly people and people with disabilities to use (Mueller, 1998). Figure 1.1 shows the OXO Good Grips peeler, which contains the thick, comfortable handle that helped make OXO Good Grips product line famous. In another popular example, Morison Cousins redesigned the Tupperware container to increase usability for people with strength and vision disabilities. Cousins’ use of handles made the containers easier to open, and his contrasting color scheme made it visually easier to separate the lids from the containers. Furthermore, he made these changes without impacting the simple appearance that consumers loved (Mueller, 1998).
Unfortunately, applying these commonly referenced case studies to new designs can be somewhat difficult because they were not all created using a general, consistent strategy. Therefore, a generalized universal design approach is needed (Beecher and Paquet, 2005). The Seven Principles of Universal Design created by the Center for Universal Design serve as a framework for creating universal designs; however, as is shown by the three examples in Section 3.4, many non-universal designs meet these Seven Principles. In other words, the principles as they currently exist do not ensure the creation of a universal design. Consequently, the proposed methodology modifies the Seven Principles of Universal Design such that non-universal designs are no longer mislabeled as universal designs. In addition, the methodology establishes universal design capability requirements to be used alongside the modified principles.

In the next chapter, an examination of the relevant literature is presented. Chapter 3 introduces a methodology for determining the capability levels needed for various types of design. Additionally, a modification to the Seven Principles of Universal Design is presented that increases their relevance as a general universal design approach. A grip strength example is presented in Chapter 4 to enhance one’s understanding of the methodology. Chapter 5 examines the proposed methods and discusses the broader impacts of the work, which include increased design universality and cheaper universal designs.
CHAPTER 2

BACKGROUND AND LITERATURE REVIEW

Designers frequently create products for a specific target population without considering the full breadth of the ranges of capabilities within that population. There exist ranges of capability levels for all skills and abilities, and all individuals perform at the lower end of these ranges for certain tasks. For example, a person using a wheelchair might have limited leg strength, but this person may also have extremely high arm strength. Therefore, the problem is really a misunderstanding of what disability and capability are. This confusion causes designers to create typical designs, or designs that fail to meet the needs of people with lower capabilities (Mpofu and Oakland, 2010). Though, there are times when typical designs are appropriate. For instance, a designer may choose to create a typical product if an existing product is already meeting the needs of people with lower capabilities. This is especially true if the designer would like to avoid competition with the manufacturer of the existing product. A typical design may also be suitable if the target population is relatively small and is known to perform well in terms of the capabilities needed for the design.

On the other end of the capability spectrum are accessible designs, or designs created specifically for people with disabilities (Stephanidis et al., 1998). Because of their focus on the reduced capabilities of people with disabilities, accessible designs often do not meet the requirements of individuals with more capability proficiency in the related areas. In other words, accessible designs tend to cater to the needs of the users in the lower tail of a capability distribution, and as a result, they often do not appeal to the users in the upper tail of the distribution. Therefore, accessible designs tend to emphasize the user’s disabilities since people without disabilities are unlikely to use them. This explains why
there sometimes exists a stigma associated with using accessible designs (Yearns, 2002). Also, designing specifically for people with disabilities may not result in a design that is best for this group of people, as these designs are often linked to high costs, a limited number of users, and unsightly appearances (Dong, 2007). However, accessible designs are sometimes necessary to meet the needs of users with unique capability limitations.

As one might guess, both people with and without disabilities can use universal designs, or designs intended to be used by everyone (Mpofu and Oakland, 2010). The term “universal design” was coined by architect and wheelchair user Ron Mace in the early 1980s (Bremer et al., 2002). He defined universal design as, “The design of products and environments to be usable by all people, to the greatest extent possible, without the need for adaptation or specialized design” (The Center for Universal Design, 2008b).

Later, in 1989, Mace went on to create the Center for Universal Design at North Carolina State University (Rossetti, 2006). The intention of the Center for Universal Design is to assist designers in creating products and designs that are usable by everyone. Their research focuses on creating design solutions that will benefit as many users as possible (The Center for Universal Design, 2008a). In 1997, the Center for Universal Design published the Seven Principles of Universal Design, which still serve as the primary guidelines for many designers intending to create universal designs (Preiser, 2008). The principles are listed in Table 2.1, with the definitions from Connell et al. (1997).

Unfortunately, most product designers cannot simply use universal design principles and guidelines to make universal products because they lack a deep understanding of what it means to create a design that is usable by everyone (Song and Lee, 2008). For this reason, Song and Lee mapped user accessibility needs to the Seven Principles of Universal Design and presented a detailed approach for conducting universal design. The results of this approach are quantitative characteristics for a product based on the accessibility needs of the target users. However, this approach is very limited in that it can only be used to design for people with one of 13 specific disabilities.
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<td>Equitable Use</td>
<td>The design is useful and marketable to people with diverse abilities.</td>
</tr>
<tr>
<td>2</td>
<td>Flexibility in Use</td>
<td>The design accommodates a wide range of individual preferences and abilities.</td>
</tr>
<tr>
<td>3</td>
<td>Simple and Intuitive</td>
<td>Use of the design is easy to understand, regardless of the user’s experience, knowledge, language skills, or current concentration level.</td>
</tr>
<tr>
<td>4</td>
<td>Perceptible Information</td>
<td>The design communicates necessary information effectively to the user, regardless of ambient conditions or the user’s sensory abilities.</td>
</tr>
<tr>
<td>5</td>
<td>Tolerance for Error</td>
<td>The design minimizes hazards and the consequences of accidental or unintended actions.</td>
</tr>
<tr>
<td>6</td>
<td>Low Physical Effort</td>
<td>The design can be used efficiently and comfortably and with a minimum of fatigue.</td>
</tr>
<tr>
<td>7</td>
<td>Size and Space for Approach and Use</td>
<td>Appropriate size and space is provided for approach, reach, manipulation, and use regardless of the user’s body size, posture, or mobility.</td>
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</table>
2.1 Is universal design achievable?

Most designers today will agree that universal design is achievable, and creating a universal design often costs no more than creating a typical design if universal design principles are considered early enough in the design phase (Mace et al., 1996). Additionally, the benefits of universal design are not limited to those who have permanent disabilities. For example, consider grocery shoppers who are attempting to open the doors to their homes with both hands full of groceries. In this case, the shoppers would certainly prefer to use a door lever rather than a doorknob, even though the lever may have actually been created for people who have trouble grasping and turning a knob (Mace et al., 1996). As a second example, consider the curb cuts that make it easier for wheelchair users to get on and off of roadside curbs. Although designed for those people with permanent disabilities, these cuts have certainly made life easier for bicyclists, skateboarders, people with strollers, and pedestrians, regardless of their capabilities (Vanderheiden, 1990).

As people age and face an increasing number of limitations, there exists some ethical obligation to continue to provide this aging population with designs that are adequate and safe. Additionally, as the population ages as a whole, there is financial incentive to consider the capabilities of the elderly. The United Nations predicts that 22% of the world’s population will be over the age of 60 by 2050, and the Federal Interagency on Aging Related Statistics predicts that 20% of the U.S. population will be over the age of 65 by 2030 (Ehrenman, 2005). Choosing to ignore such a large percentage of the population would surely limit a design’s relevance and potential revenue. Even if moral and financial reasons fail to motivate a designer to consider universal design, Section 508 of Public Law 99-506 and the Americans with Disabilities Act legally require many designs to be inclusive of people with disabilities. Therefore, universal design is not only achievable, but it is quickly becoming a requirement in many designs for ethical, financial, and legal reasons (Marshall et al., 2010).

It is important to note that universal design as previously defined is achievable, while universal accommodation is usually not possible. In other words, it is possible to create a universal design that is suited for a wide range of capability within a population;
however, it is difficult, if not impossible, to create a design that truly accommodates everyone.

2.2 Designing for Human Variability

The subject of Designing for Human Variability often focuses on creating products and designs that are usable by a given percentage of the population. For example, a designer may attempt to design a chair’s height, width, and seat depth such that it is usable by 95% of the people in a database representative of the target population. Based on this information, one might then assume that universal design would simply attempt to create a chair that is usable by every person in the given database; however, this logic is incorrect. Most databases used for design typically do not represent the full spectrum of capability exhibited by the target user population (Vanderheiden, 1990). Therefore, designing for everyone in the database would still exclude many people with disabilities in the population for which the design is being created. It would be unrealistic to assume that a design could be created that would truly accommodate everyone because of the large range and variety of human capability and size that exist. Additionally, people with similar anthropometric or capability measurements may interact with a design differently due to differences in user preference (Garneau and Parkinson, 2009). Therefore, universal design attempts to accommodate as many people as possible in a population consisting of both people with and without disabilities, while realizing that the exclusion of some people from a design is inevitable.

Marshall et al. (2010) created a design tool, HADRIAN, that uses a database of individuals’ anthropometry and capability to evaluate the inclusiveness of a design. While the HADRIAN database consists of many elderly people and people with limited capability, the focus of the data collection effort was to span the ranges of capability and anthropometry that existed for all measures. These data can be used to evaluate the inclusiveness of proposed designs by predicting how users will interact with those designs. However, people will always interact with designs in unpredictable ways. This somewhat limits HADRIAN’s applicability because HADRIAN can only predict user
interaction based on users’ interactions with existing designs. These predictions may or may not accurately represent how users will interact with a proposed design.

2.3 Human capability

Since universal design centers around creating designs that are usable by both people with and without disabilities, it is important to clarify what it means to have a disability. As one might suspect, there is no defining line that separates people with and without disabilities. Instead, there exists a range of capabilities for any given skill or ability. Additionally, those who fall at the lower end of the range for a given skill or ability may excel at other skills or abilities (Vanderheiden, 1990).

Gregor et al. (2002) argue that the large variety of functionality that exists in people makes it hard to create a design that is truly inclusive of everyone. However, by using capability data for a given measure for both people with and without disabilities, designers are better able to evaluate designs and how they cater to the ranges of capabilities that exist.

One approach to universal design is to focus on capability: creating products, tasks, and environments that work for as broad of a range of capability as possible. This mentality can be applied to evaluating and modifying existing designs, where capability data can be used to indicate users that are being disaccommodated. Changes can then be proposed based on responses to those exclusions (Dong, 2007). This suggests that some form of capability data could be used to create universal designs. These capability data enable designers to quantitatively include people whose needs would traditionally not be considered. Fortunately, data on human capabilities, and especially human strength, already exist. These data become even more useful when paired with anthropometric databases because it becomes possible to identify relationships between capability and anthropometry.
2.4 Anthropometric data

Anthropometric databases consist of measurements of the human body, and therefore, designers can use anthropometric data when determining product sizing. Sizing products based on body measurements leads to products that are better suited for the intended users’ anthropometry. Although it is usually ideal for designers to collect anthropometric data directly from their target populations, time and cost constraints often prevent this from being possible. Fortunately, there are a number of publicly available anthropometric databases that designers can use to represent their target populations. Before doing so, however, it is important that they acknowledge any differences between the individuals measured for the databases and the users for whom they are designing. These could include differences in age, gender, mobility, and ethnicity, among others.

2.4.1 NHANES

The National Health and Nutrition Examination Survey (NHANES) consists of a group of studies that are conducted by the U.S. Centers for Disease Control and Prevention (CDC). The studies began in the 1960s and became a continuous group of studies in 1999. Since then, approximately 5,000 people across the United States participate in the studies every year, which consist of interviews and various medical, dental, and physiological assessments. These studies also include several important anthropometric measurements, such as stature and weight (National Center for Health Statistics, 2007). Every two years the CDC releases the results of the NHANES study, with the data from the 2007-2008 study being the data most recently made available (U.S. Centers for Disease Control and Prevention, 2008).

Each NHANES participant is assigned a demographic weight, which indicates the number of people the person demographically represents in the U.S. population. Therefore, the weights of all participants should sum to the entire U.S. population. This weighting procedure allows the CDC to increase the accuracy of the survey by oversampling the tails of distributions. Specifically, NHANES over-samples African Americans, Hispanics, and people over the age of 60 (National Center for Health Statistics,
2007). Over-sampling these groups of people creates a sample size large enough to accurately analyze the variation that occurs among these people. This analysis provides NHANES with a better idea of the true range of variability exhibited by a population. The demographic weights of the participants in the over-sampled populations are then reduced so that the survey does not misrepresent their existence in the actual U.S. population.

### 2.4.2 U.S. flying personnel

In 1967, the U.S. Air Force conducted an anthropometric survey of male flying personnel. The survey measured 186 anthropometric measures on 2,420 males, and the survey also recorded grip strength for all participants (Grunhofer and Kroh, 1975). A similar survey of female flying personnel was conducted in 1968, consisting of 1,905 females. The female survey consisted of 123 anthropometric measurements, in addition to grip strength (Clauser et al., 1972).

These surveys are particularly beneficial because they collected both grip strength data and anthropometric data, as opposed to just one or the other. Therefore, regression modeling can be used to determine what relationships between grip strength and the various anthropometric measurements exist. These relationships can then be applied to more recent sets of data, such as the data from NHANES, in order to predict the grip strengths of participants from more recent data collection surveys.

### 2.4.3 ANSUR

The Anthropometric Survey of U.S. Army Personnel collected measurements from 1,774 men and 2,208 women in the U.S. Army from 1987-1988. The Anthropometric Survey (ANSUR) was conducted to address demographic changes within the U.S. Army that had not been captured by previous anthropometric studies. These changes included a shift in racial composition and an increasing number of female personnel (Gordon et al., 1989). ANSUR also addressed the lack of publicly-available anthropometric data for civilians, providing civilian designers with a data source to use whenever civilian data were unavailable (DOD, 1991).
ANSUR data are particularly valued because of the large number of measures collected. Proportionality constants (Drillis and Contini, 1966), linear regression (Nadadur and Parkinson, 2008), and other techniques (Parkinson and Reed, 2010) can be used to relate the various measurements to each other, and these relationships can then be used to predict the anthropometry of individuals for whom certain measurements are unknown. An additional benefit of ANSUR is that it contains data on ethnicity and birthplace, which could be used to explain differences and correlations among measurements (Kues, 2008).

One of the major drawbacks of ANSUR is that it surveyed people from a military population. This limits the applicability of the data for people outside of the military because of the differences in fitness levels and demographics between military and civilian populations. Additionally, the U.S. Army places limits on certain anthropometric measurements of its recruits, effectively clipping the tails of anthropometric distributions (Military Advantage, 2010). Another drawback of ANSUR is that it has become somewhat outdated, meaning that it does not take into account any secular trends that have occurred since it was created.

2.4.4 CAESAR

The Civilian American and European Surface Anthropometry Resource Project (CAESAR) collected three dimensional (3D) surface scans of 2,400 U.S. and Canadian civilians and 2,000 European civilians from 1998-2000. The body surfaces of the participants were scanned while they posed in three different positions. These surface scans enabled the collection of hundreds of thousands of 3D surface points in a matter of seconds. The surface points can be used to measure the participants’ anthropometry, even when the participants are no longer present (SAE International, 2010).

The volunteer participants wore cotton bicycle shorts and latex caps, and the women also wore gray sports bras (Allen et al., 2003). This indicates that CAESAR may not be representative of the entire population because it consists of only those individuals who were willing to be scanned in minimal clothing. Furthermore, no attempt was made to select participants such that the data would be collected from a representative population.
2.4.5 Anthropometry of children

Prior to the 1970’s, very little anthropometric data of children were readily available. Much of the data that did exist were not representative of large populations and the measures were not well defined (Snyder et al., 1975). The Consumer Product Safety Commission (CPSC) determined that it was necessary to have these data to design safe products for children, and in 1975 they sponsored a study run by the Highway Safety Research Institute to collect anthropometric measurements from children. The study collected 41 measurements from 4,027 children ranging in age from 2-weeks-old to 13-years-old (Snyder et al., 1975). In 1977, the CPSC sponsored a second study run by the Highway Safety Research Institute. This study was similar to the 1975 study; however, it collected 87 measurements from 4,127 children ranging in age from 2-weeks-old to 18-years-old (Snyder et al., 1977). The anthropometric data obtained from these two studies are still used more than any other set of children’s anthropometric data (Reed, 2010).

2.5 User accommodation

User accommodation refers to the number of people who are not inconvenienced by the limits of a design (Roe, 1993). Whether or not an individual will find a design convenient is largely based on how the design fits that individual, with the definition of fit greatly dependent upon the design itself (HFES 300 Committee, 2004).

Garneau and Parkinson (2009) explore three different approaches to achieving accommodation, which they define as, “the degree to which a design meets the needs of the user population.” They explore boundary manikins and population models, which have been used extensively in user accommodation. They then discuss a hybrid approach, which combines several of the advantages of both boundary manikins and population models.

The general premise behind boundary manikins is that by accommodating users at the extreme ends of a scale, all of the users within those extremes will also be accommodated. For example, a chair designer may choose to design the width of a seat for 95% of the
chair’s potential users. To do this, the designer would need to find the 95th-percentile seated hip breadth of the target population. The designer may alternatively choose to use a database representative of the target population, such as NHANES or ANSUR, to determine the 95th-percentile seated hip breadth. The seat width would then be set equal to this 95th-percentile value.

In the previous example, it was assumed that the chair would accommodate everyone having a smaller seated hip breadth than the 95th-percentile value. However, the underlying assumption of boundary manikins does not always hold true. In other words, designing for the extremes does not always accommodate everyone within those extremes. This occurs because no boundary manikins can simultaneously represent the anthropometric variability that exists within a population (Bittner, 2000). User preference also helps explain why this disaccommodation occurs. For instance, some individuals may prefer to sit towards the side of a chair, while other individuals may prefer to spread out their legs. Therefore, these users may not be accommodated by a chair designed for the 95th-percentile seated hip breadth even if their individual seated hip breadths are smaller than the 95th-percentile value. Another problem with boundary manikins is that anthropometric proportions are not constant for all people. In other words, a person with a 5th-percentile stature generally does not have 5th-percentile arm and leg lengths (Roe, 1993).

Boundary manikins are also unreliable for design purposes if they are not first placed in the correct posture (Reed et al., 2002). This posture, determined by user preference, must be accurately predicted before any worthwhile analysis can be conducted. Therefore, Reed et al. create a new population model for posture prediction in driving vehicles based on a study of 68 men and women.

Population model approaches to design are different from boundary manikin approaches in that they require a physical prototype. Continuing the previous chair example, a population model could be created for the chair if a physical prototype of the chair existed. Potential users would then need to sit in the chair prototype and adjust the width of the chair to the width that they desired. The main advantage of this approach is that the designer does not have to worry about user preference because
users are adjusting the prototype to their desired settings regardless of their individual anthropometry. Additionally, it may be possible to learn something new about the product simply by watching the test users interact with the prototype. However, the advantages of population models are offset by the fact that the designer needs to create an adjustable prototype, which can be expensive. Also, the data obtained from this approach are not reconfigurable, meaning that these data are only applicable to the population from which they were obtained.

As mentioned previously, Garneau and Parkinson (2009) combine the advantages of boundary manikins and population models into a hybrid design approach. Like a population model, a hybrid model also requires a physical prototype; however, the data obtained from using this prototype are reconfigurable to additional populations via regression. By regressing user preference data with anthropometry, it is possible to predict the preferences of additional populations based on the populations’ anthropometry.

Hybrid models include a residual variance term that models the distinct behavior of individuals across a population. This residual variance term is assumed to be normally distributed with a mean of zero and a variance equal to the mean square error (MSE) of the model. Including this error term enables the model to assign different preference values to individuals with the same anthropometry. This accounts for the fact that two individuals with the same anthropometry will not necessarily have the same preferences.

A method similar to they hybrid model approach to accommodation can be used to create anthropometric linear regression models. By including a residual variance term in the regression model, it is possible to use the anthropometry of one population to predict the anthropometry of another population. This approach to creating anthropometric linear regression models is explored in Section 3.2.

2.6 Chapter summary

This chapter defined typical, accessible, and universal designs and introduced the Seven Principles of Universal Design. Universal design is an achievable design approach that can be used to create products that are better suited for the entire population, regardless of
disabilities. Since it can be difficult to define what it means to be disabled, people creating universal designs should instead focus on the ranges of capabilities that exist among the target users. In instances where capability data is unavailable, a hybrid model can be used to predict the target users’ capabilities. In the next chapter, a methodology is introduced for using capability data to establish design targets for typical, accessible, and universal designs.
CHAPTER 3

METHODOLOGY

The main objective of this research is to increase design universality by establishing specific, recommended strategies for creating and assessing typical, accessible, and universal designs. Capability requirements will clarify any confusion that exists between the design types, thus enabling designers to better evaluate the universality of designs. The capability requirements can then be used alongside the Seven Principles of Universal Design to create designs that are better suited for the entire population. A second research objective is a suggested modification to the Seven Principles of Universal Design such that they more accurately describe universal designs. This modification will assist designers in the design decision-making process as they strive to create designs that are usable by all.

3.1 Proposed methodology

A series of steps are necessary to establish the capability requirements for a given design. First, the designer must specify the target user population. As was discussed in Chapter 2, this population determines whether the design should be a typical, accessible, or universal design. After defining the target population, the designer must determine what capability data are necessary for the proposed design. If the designer cannot obtain these data directly from the target population, a capability database can be used.

If the chosen capability database is not demographically representative of the target population and anthropometric data for the target population are available, the relationship between capability and anthropometry must be determined. This relationship can then be used to predict the capabilities of the individuals in a database,
such as NHANES, that more accurately represents the target population. This procedure is discussed in Section 3.2.

The capability data are then weighted depending upon the type of design being created. For a typical design, the capabilities need to be weighted such that they reflect their prevalence in the actual target population. For an accessible design, these weights must be modified so that the lower capabilities are emphasized. For a universal design, no weighting is necessary. The designer instead focuses on the entire range of capabilities that exists, treating all capabilities equally regardless of their prevalence in the actual population. After any necessary weighting has occurred, capability requirements can be calculated. Establishing weights and calculating capability requirements is discussed in Section 3.3. Figure 3.1 summarizes the proposed methodology, which is discussed in more detail throughout the remainder of this chapter.
Figure 3.1: Methodology summary. This flowchart outlines the steps necessary to implement the proposed methodology.
3.2 Relating capability to anthropometry

As mentioned in Section 2.4.2, linear regression can be used to relate capability to anthropometric measurements. This relationship in one database can then be used to predict the capabilities of individuals in another database. The regression analysis would result in an equation similar to the one shown in Equation 3.1, with Y and Z representing real numbers.

\[ \text{CapabilityMeasurement} = Y \times \text{AnthropometryMeasurement} + Z \]  

Equation 3.1 could be used directly to estimate the capability of any individual based on that individual’s anthropometry; however, this calculation would ignore the fact that there is some variation associated with these equations. In other words, two people with the same anthropometry will not necessarily have the exact same capability. Garneau and Parkinson (2010) include residual variance in their hybrid model of preferred bicycle seat height to account for the fact that two individuals with the same stature will not necessarily prefer to have their bicycle seat placed at the exact same height. As mentioned in Section 2.5, a similar approach can be used to account for the variation in capability among individuals with the same anthropometry, assuming that residuals are normally distributed and uncorrelated. A stochastic error term can be added to Equation 3.1 in order to make up for the fact that anthropometry alone cannot define capability. This stochastic term is assumed to be normally distributed, and the distribution is assumed to have a mean of zero based on the standard assumptions of regression. The variance of this distribution is equal to the MSE of the linear regression model (Flannagan et al., 1998). Equation 3.1 is modified to include the stochastic error term shown in Equation 3.2.

\[ \text{CapabilityMeasurement} = Y \times \text{AnthropometryMeasurement} + Z + N(0, \text{MSE}) \]  

Once a database representative of the target population has been chosen, it is possible to use Equation 3.2 to predict the capabilities of the individuals in the database based on their anthropometry. Although the specific capability assigned to any one person is likely different from that individual’s actual capability, distributions across a large, virtual
population are similar to those of the actual participants. Therefore, designers are able to use this predicted capability in the same way that they would use measured capability values, had they originally been included in the database that is representative of their target population.

3.3 A new approach to quantifying population capability

The purpose of this section is to define a new approach to quantifying population capability for design purposes. This approach determines the capability requirements of a design such that they will adhere to the ranges of capabilities that exist in the target population. Designers can use this approach to verify whether or not a design will meet the capability needs of its intended users.

The capability needed to use a given design will depend upon whether the design type is intended to be typical, accessible, or universal. The method used to obtain the minimum required capability for a design will also depend upon the design type. Therefore, a designer must first determine what type of design will be created before determining the minimum capability level that will be necessary to use the design. Once the design type has been decided upon, the individuals within the designer’s representative database can be weighted in a way that reflects the design’s target user population. In other words, each individual can be assigned a unique weight that indicates how strongly that individual’s measurements influence the user population as a whole.

Population capability is then quantified through the use of percentiles for typical and accessible designs. This means that the capabilities of the individuals in the representative database should be arranged in increasing order. Then, the designer can determine the capability level that a given percentage of the population is able to achieve. For typical designs, the percentile is calculated after the database has been weighted to reflect the capabilities of the target population. For accessible designs, the database is weighted such that it emphasizes the individuals with lower capabilities to the exclusion of more capable members.
For universal designs, population capability is quantified by calculating a percentage of the range of capabilities that exists. The capabilities do not need to be weighted because they are all considered equally. In other words, a capability level is considered equally important whether it is possessed by one person or 100 people.

### 3.3.1 Typical designs

For a typical design, the designer’s representative database must be weighted such that it demographically represents the target population. These weights are often provided by the designers of the database; however, the data can be re-weighted to represent different design populations (Nadadur and Parkinson, 2009). A percentile can then be calculated from this weighted database in order to determine the design’s capability level requirement. This percentile reveals the percentage of the weighted population that falls under a given capability, and the percentile is chosen based on the designer’s desired accommodation level.

### 3.3.2 Accessible designs

Determining the capability level necessary for an accessible design is slightly more challenging than creating a typical design since the participant weights must be modified to emphasize the needs of the individuals with reduced capabilities. Individuals with reduced capabilities are frequently not included in anthropometric surveys, and the surveys that focus on these individuals are generally small in size and specific to a particular design (Case et al., 2001). By overweighting the lower capabilities in an anthropometric database, it is possible to account for the numerous individuals with reduced capabilities who were not included. Equations 3.3 and 3.4 can be used to create the weights for an accessible design population. Equation 3.3 calculates an individual’s temporary accessible weight $T_i$, which is then used in Equation 3.4 to calculate an individual’s actual accessible weight $A$.

$$T_i = W_i \cdot (1 - p_i)^X$$  \hspace{1cm} (3.3)
In Equation 3.3, \( i \) represents the individual for whom the calculation is being performed, \( T \) represents a temporary accessible weight, \( W \) represents the individual’s demographic weight as determined by the designers of the database, \( p \) represents the capability percentile of the individual for whom the temporary accessible weight is being calculated, and \( X \) represents the degree of accessibility. The variables used in Equation 3.4 represent the same values as the variables in Equation 3.3, with the addition of a variable \( A \) that represents the individual’s Accessible Weight and a variable \( n \) that represents the total number of individuals in the database.

A temporary accessible weight is first calculated for each individual, \( i \), using Equation 3.3. This equation amplifies the demographic weights of the individuals whose capabilities are far from the maximum capability by multiplying them by a capability index, or \((1 - p_i)^X\). However, the temporary accessible weight obtained from Equation 3.3 cannot be used directly for design. As mentioned in Section 2.4.1, a participant’s demographic weight indicates the number of people that participant represents in the actual population. Therefore, the demographic weights should sum to the number of people living in the actual population. Since Equation 3.3 decreases the demographic weights of all participants, the temporary accessible weights must then be scaled up in a way that increases the sum of the weights to the actual population. Equation 3.4 accomplishes this task by multiplying the temporary accessible weights from Equation 3.3 by a scaling term. To verify that the weights have been properly scaled up, one should sum the accessible weights obtained from Equation 3.4 and confirm that this sum is equal to the sum of the demographic weights \( W \) for the entire population.

The value chosen for \( X \) must be specified by the designer based on the degree of accessibility he or she would like to achieve with the design. As the value of \( X \) increases, so does the number of people who will be able to use the design. One of the easiest ways to determine the desired degree of accessibility is to create a visual depiction of the
users’ capabilities, weighted using the temporary weights $T$ obtained from Equation 3.3. Creating a histogram of the weighted capabilities illustrates how much emphasis will be placed on designing for individuals with lower capabilities. A value of 57 generally serves as a good starting point for $X$ because this value calculates the accessible weights such that the bottom 5% capabilities account for approximately 95% of the capability indices. Figure 3.2 shows how the capability indices of the bottom 5% capabilities change as the value of $X$ changes. The degree of accessibility can then be increased or decreased based on the designer’s intentions. Setting the degree of accessibility equal to 0 eliminates the capability index term from Equation 3.3. Without this term, the accessible weights are effectively the same as the demographic weights used to create a typical design. Thus, the degree of accessibility can theoretically range from 0 for typical designs to infinity for accessible designs, but using a value greater than 57 can greatly increase design costs with minimal change in usability. Figure 3.3 shows how a weighted histogram of capabilities changes as the value of $X$ changes, and Figure 3.4 shows how changing the value of $X$ affects the capability indices assigned to different capability percentiles.

After the degree of accessibility has been decided upon and the weighted distribution of capabilities has been created, it is possible to determine the capability level to use in a proposed design. Unlike a typical design, where the goal is to accommodate a given percentage of the population, the goal with an accessible design is to accommodate a given percentage of the accessibly-weighted capabilities. Therefore, a percentile value is calculated from the accessibly-weighted capabilities.

### 3.3.3 Universal designs

Universal designs are different from typical and accessible designs in that the focus is entirely on the ranges of capabilities that exist in the population. Although the capabilities at the lower and higher end of the spectrum generally occur less frequently in a given population than the capabilities in the middle of the spectrum, all capabilities are considered equally when creating a universal design. Therefore, calculating the capability necessary for a universal design is fairly simple since the frequency of occurrence for each capability is not considered. Although analyzing a range of capabilities is similar to
increasing the weights of the individuals at the tails of the capability distribution, ranges are used instead of weights because of their ease of calculation.

To obtain a universal capability, one must simply calculate a percentage of the entire range of capabilities that exists for a specific skill or ability. This percentage is then subtracted from the maximum capability in order to arrive at a universal capability requirement. This capability requirement will require more capability than an accessible design, as accessible designs are created specifically for those users with lower capabilities. Accordingly, a universal design meant for “everyone” must entail more than merely the capability needed to use it. Section 3.4 explores the features of a universal design that separate it from an accessible design.
Figure 3.3: Comparison of weighted capability histograms for grip strength, with varying degrees of accessibility $X$. Increasing the value of $X$ increases the emphasis placed on individuals with lower capabilities. Generally, setting $X$ equal to 57 is a good starting point, which is shown in Figure 3.3c. Figures 3.3b and 3.3d show how the weighted histogram changes when $X$ is decreased to 43 and increased to 71, respectively. Figure 3.3a shows what happens when $X$ is set to zero, which eliminates the capability index term from Equation 3.3.
Figure 3.4: The effect of $X$ on capability index. Increasing the value of $X$ decreases the capability indices assigned to individuals with higher capabilities.
3.4 Modifying the Seven Principles of Universal Design

The Seven Principles of Universal Design have already undergone some changes for several specific applications. For instance, Scott et al. (2003) discuss modifying the Seven Principles of Universal Design for instructional purposes in schools. However, changes need to be made to the Seven Principles of Universal Design for general design purposes. The problem with the principles as they currently stand is that many accessible designs follow all seven of the Seven Principles of Universal Design. Therefore, a designer intending to create a universal design could end up mistakenly creating an accessible design if he or she were to use the existing principles.

Although reduced capability requirements are a defining feature of universal designs, a universal design is not simply a design that requires fewer capability requirements than a typical design. If that were the case, an accessible design would undoubtedly be a better alternative than a universal design for those users with lower capabilities. In an attempt to capture the defining aspects of universal design, The North Carolina State University Center for Universal Design created the Seven Principles of Universal Design discussed in Chapter 2. These principles, which were created after an extensive review of products, architecture, and building components, were intended to be used to both evaluate existing products for universality and to assist in the design of new universal products (Story et al., 1998). They also stand as the primary guidelines for designers intending to increase design universality (Preiser, 2008). Some researchers have even taken the Seven Principles of Universal Design one step further by developing ways to quantitatively evaluate their inclusion in a given design. For instance, Beecher and Paquet (2005) developed a survey instrument to measure a given design’s compliance with the Seven Principles of Universal Design. Though, it is necessary to take a step back and evaluate the design principles themselves before more time is spent building upon them. Analyzing these principles reveals that the principles as they currently exist may not entirely describe the components of universal design.

Consider the grouping of scissors shown in Figure 3.5. Figure 3.5a shows a typical pair of Fiskars right-handed scissors. These scissors feature slanted grooves in the finger
openings that make holding and operating the scissors more comfortable for right-handed users. However, these grooves can also make using the scissors more difficult for individuals who need or want to use the scissors with their left hand. Figure 3.5b shows an accessible pair of scissors that can be used equally well with either the right or left hand. Additionally, these scissors do not require the user to apply any opening forces as the blue band is able to open the scissors on its own. Therefore, the accessible scissors are better suited for someone who has reduced finger capability, and they do not discriminate against users who have a higher capability in one hand than they do in the other. The universal scissors shown in Figure 3.5c are similar to the accessible scissors in that they can be used by either hand and they do not require any opening forces. In this case, a spring is responsible for opening the scissors after they have been closed.

The key difference between the scissors in Figures 3.5b and 3.5c is how they approached the task of increasing usability. The universal scissors increased usability while maintaining a somewhat similar appearance to the typical scissors, while the accessible scissors added a rather unsightly blue band. If anything, users may find the appearance of the universal scissors to be more attractive than the typical scissors, although few would choose the accessible scissors over the typical scissors based solely on appearance. Therefore, the universal scissors increased usability while potentially also improving the scissors’ appearance, but the accessible scissors increased usability potentially at the cost of user acceptance.

The grouping of remote controls shown in Figure 3.6 helps further clarify the difference between typical, accessible, and universal designs. The remote shown in Figure 3.6a is a typical remote control with small buttons and text. It can be difficult to read, and the small buttons could make it difficult to press the correct button, especially for someone with large fingers. Additionally, the variations in button color, size, shape, and layout make operating this remote confusing. The accessible remote control in Figure 3.6b attempts to alleviate some of the problems associated with the typical remote by increasing the size of the remote and the remote’s buttons. The accessible remote also has less button size and shape variation and simpler wording than the typical remote, making it easier for someone with lower cognitive abilities to operate the remote. The universal remote
control—“universal” in this sense referring to capability and not the ability to be used with multiple electronic devices—in Figure 3.6c also has a larger size and a simpler layout than the typical remote; however, it has a heart shape and is pink in color.

The unique shape and color of the universal remote helps set it apart from the accessible remote. Although the accessible remote reduces the capabilities needed for operation, it also varies the overall appearance of the product in order to accomplish this task. Similarly, the universal remote modifies the appearance of the product in order to
increase usability, but it does it in a way that will appeal to additional users. For example, teenage girls may choose to purchase this remote entirely for its appearance. This seems to indicate that a universal design is different from an accessible design in that it is marketable for reasons beyond increased usability.

The grouping of shoes in Figure 3.7 reveals that leaving a design’s appearance unchanged can be used as an alternative to making appearance improvements when creating a universal design. Figure 3.7a shows a typical dress shoe that would be similar to a dress shoe found in any traditional shoe store. The laces on this shoe could be difficult to tie for someone with lower finger capabilities or for someone who does not have the ability to use both hands to tie shoelaces. The accessible shoe in Figure 3.7b eliminates the need to tie shoelaces by replacing them with velcro straps. The universal shoe in Figure 3.7c also eliminates the need to tie shoelaces by replacing the standard laces with stretchable shoelaces. These shoelaces are capable of stretching while remaining tied so that the user can simply slip his or her foot in and out of the shoe without having to worry about tying or untying any laces.

Although the accessible and universal shoes both prevent the user from having to tie or untie shoelaces, only the universal shoe hides the fact that it is different from the typical shoe. The velcro straps on the accessible shoe highlight that the user may be unable to use shoelaces, which may make the wearer feel ashamed or embarrassed. Meanwhile, the universal shoe looks no different than the typical shoe, thus allowing the user to feel more relaxed and at ease while wearing it. The convenience of not having to tie or untie shoelaces may even attract users with high finger capabilities to the universal shoe because of the universal shoe’s identical appearance to a typical shoe.

The examples in this section reveal two important aspects of universal design that are not addressed by the Seven Principles of Universal Design. First, leaving a design’s aesthetics unchanged helps hide a user’s lack of capability. In the shoe example in Figure 3.7, this was accomplished by leaving the appearance of the universal shoe entirely unchanged from the appearance of the typical shoe, while greatly reducing the shoe’s capability requirements. However, if a universal design will modify the aesthetics of a typical product, it must do so in a way that improves upon the product’s appearance.
Figure 3.6: Comparison of remote control designs. The remote in Figure 3.6a has a multitude of buttons that are arranged in various patterns alongside fairly small text. The remote in Figure 3.6b has much larger buttons than the remote in Figure 3.6a, and it is generally easier to read and understand. The remote in Figure 3.6c also features large buttons with large text, but the heart shape makes it marketable for reasons other than usability.
There are two different ways this improvement can occur. As seen in the scissors example in Figure 3.5, the appearance could be made more stylish and elegant. In this case, the appearance modifications must be ones that would generally increase product appeal, even if usability improvements were not being included in the design. The other method of improving appearance would be to change the design so that it is marketable to new users for reasons other than usability improvements. This is the approach illustrated by the remote control example in Figure 3.6.

Based on these examples, it is necessary to modify the Seven Principles of Universal Design to include an eighth principle. This principle, Attractive Appearance, includes three new guidelines that cover the aspects of universal design captured by the previous three examples:

- Whenever possible, create the universal design such that it looks identical to the typical version of the design.
- Ensure that any changes in appearance would improve the design as a whole, even if the design’s usability remained unchanged.
- Use appearance changes to attract new users to the design.
Figure 3.7: The shoe in Figure 3.7a is a men’s shoe with tied shoelaces. The shoe in Figure 3.7b uses velcro rather than shoelaces for those users who are not able to or do not know how to tie shoelaces. The shoe in Figure 3.7c has shoelaces that are capable of stretching. Users who have difficulties with shoelaces can use the shoes in Figure 3.7c without emphasizing their lack of capability, as the stretchable shoelaces look identical to the shoelaces seen in other typical shoes.
3.5 Chapter summary

This chapter explained how capability data can be used to establish design requirements for typical, accessible, and universal designs. This included methods for weighting the capability data based on the type of design being created. This chapter also explained how the target users’ capabilities can be predicted whenever the available data is not representative of the target population. Since universal design capability requirements are intended to be used alongside the Seven Principles of Universal Design, these principles were modified to more accurately describe universal designs. In the next chapter, the proposed methodology is demonstrated by using capability data to establish design requirements for three pairs of scissors.
The purpose of this chapter is to demonstrate the methods presented in Chapter 3 for calculating design capability requirements. These methods are used to determine grip strength design targets for a pair of typical, accessible, and universal scissors, such as the ones shown in Figure 3.5. The scissors are created for a U.S. population, and therefore, the NHANES database is used to represent the target population.

4.1 Relating grip strength to stature

Grip strength data is needed to determine the capability requirements for the three pairs of scissors. The 1967 and 1968 U.S. flying personnel surveys can be used to supply these data as these surveys measured grip strength in addition to anthropometry (Grunhofer and Kroh, 1975; Clauser et al., 1972); however, the individuals within these databases are likely not representative of the entire U.S. population. Therefore, the relationship between grip strength and stature must be determined. This relationship can then be used to predict the grip strengths of the individuals in the NHANES database, assuming that this relationship is applicable to all people.

Linear regression can be used to determine the relationship between grip strength and stature. This regression analysis resulted in Equation 4.1 for males and Equation 4.2 for females. Grip strength is measured in kilograms-force (kgf), and stature is measured in centimeters (cm).

\[ \text{MaleGripStrength} = 0.040189 \times \text{MaleStature} - 14.8873 \]  
(4.1)

\[ \text{FemaleGripStrength} = 0.02802 \times \text{FemaleStature} - 15.5293 \]  
(4.2)
As discussed in Section 3.2, two people with the same stature will not necessarily have the exact same grip strength. Therefore, a stochastic error term can be added to Equations 4.1 and 4.2 in order to account for the fact that stature alone cannot define grip strength. The MSEs of the linear regression models in Equations 4.1 and 4.2 were 51.6013 and 29.7066, respectively. Based on these MSEs, Equations 4.1 and 4.2 are modified to include the stochastic error terms shown in Equations 4.3 and 4.4.

\[
\text{MaleGripStrength} = 0.040189 \times \text{MaleStature} - 14.8873 + N(0, 51.6013) \quad (4.3)
\]

\[
\text{FemaleGripStrength} = 0.02802 \times \text{FemaleStature} - 15.5293 + N(0, 29.7066) \quad (4.4)
\]

Equations 4.1 and 4.2 had \(R^2\) values of 0.1071 and 0.0871. These values seem to indicate that the regression equations do not accurately predict grip strength; however, this is accounted for by including the error terms in Equations 4.3 and 4.4.

### 4.2 Calculating grip strength statistics

It was assumed that the target population was well-represented demographically by the individuals who participated in NHANES from the years 2003-2006. Therefore, Equations 4.3 and 4.4 were used to assign a grip strength value to each 2003-2006 NHANES participant over the age of 18 based on the participant’s stature. This created a database of grip strength values that mimics the actual grip strengths of the NHANES participants, assuming that the relationship between grip strength and stature for U.S. flying personnel is applicable to the NHANES participants. The following subsections demonstrate how these data can be used to design typical, accessible, and universal designs.

#### 4.2.1 Typical scissors

When creating a typical pair of scissors, the NHANES participants must be weighted so that the NHANES population is representative of the actual U.S. population in terms of demographics (U.S. Centers for Disease Control and Prevention, 2006b). The weights for the 2003-2004 and 2005-2006 NHANES participants were released by the U.S. Centers for
Disease Control and Prevention as part of the 2003-2004 and 2005-2006 NHANES studies, respectively (U.S. Centers for Disease Control and Prevention, 2006a, 2004). These studies include data on 20,900 participants.

After all of the participant data have been weighted, percentiles can be calculated based on the weighted NHANES database. These percentiles are obtained by determining the grip strength under which a given percentage of the participants fall. For instance, 22.29 kgf is the grip strength that 5% of the weighted, NHANES participants fall under when using their predicted grip strength values. The typical design should then be created such that it requires no more than 22.29 kgf of grip force if the goal is to accommodate 95% of the population. The weighted capability histogram in Figure 4.1 reveals the distribution of the typical population, and it highlights the males and females who would be included by a design requiring 22.29 kgf of grip force.

### 4.2.2 Accessible scissors

Equations 3.3 and 3.4 can be used to weight the grip strength data to emphasize lower capabilities when creating an accessible pair of scissors. An accessible weight was assigned to each individual in the NHANES database using these two equations. As
Figure 4.2: Weighted capability histogram for the accessible population using a degree of accessibility of 57. The blue portion of the histogram indicates the 95% of the weighted capabilities that would be accommodated by an accessible design requiring 12.42 kgf of grip force.

discussed in Section 3.3.2, 57 is generally a good value to use for the degree of accessibility. Therefore, a degree of accessibility of 57 was chosen to perform the accessible weight calculations; however, a higher or lower value could have been chosen based on the designer’s desired accessibility. Assuming that it is desired to accommodate 95% of the accessibly-weighted capabilities, it is necessary to determine the 5\textsuperscript{th}-percentile accessibly-weighted capability value. This capability value is 12.42 kgf of grip force, and it accommodates 99.91% of the population. In other words, the proposed design should be created such that it requires no more than 12.42 kgf of grip force if 95% of the accessibly-weighted capabilities are to be accommodated by the design. The weighted histogram in Figure 4.2 depicts the capabilities that would be included by a design requiring 12.42 kgf of grip force.

4.2.3 Universal scissors

Since 5\textsuperscript{th}-percentile values (indicating 95% accommodation) were used in the typical and accessible examples, 95% accommodation will once again be the goal of this example. In this example, however, the goal is to accommodate 95% of the range of capabilities that exists within the population. Since the capabilities at the high and low ends of a
capability distribution generally occur far less frequently than the capabilities in the center of the distribution, the percentage of people accommodated by this design will be far greater than 95%. Therefore, equally designing for all capabilities enables a designer to accommodate nearly everyone while still accounting for the fact that a design can never truly accommodate all people (as discussed in Section 2.2).

The smallest predicted grip strength for the NHANES participants was 10.41 kgf, while the largest predicted grip strength was 89.16 kgf. Therefore, a range of 78.75 kgf exists among the predicted grip strengths of the NHANES participants. Since the percentage value is not affected by any sort of weighting, one can simply calculate 95% of 78.75 kgf and subtract this percentage from 89.16 kgf (the largest capability value). Following this procedure results in a universal capability of 14.35 kgf, which accommodates 99.84% of the population. In other words, the universal scissors should require no more than 14.35 kgf of grip force.

4.2.4 Results summary

The results are summarized in Table 4.1, which indicates the grip strength requirement for each design type. It is interesting to point out that the capability obtained from the universal example (14.35 kgf) lies between the capabilities obtained from the typical example (22.29 kgf) and the accessible example (12.42 kgf). This confirms that a universal design will better meet the needs of all users than a typical design because of the reduced capability requirements. This also supports the idea that a universal design will never be able to meet the needs of all individuals. Specifically, a universal design will not meet the capability needs of all users as well as an accessible design that was designed specifically for an individual or a small group of individuals. However, universal designs are generally better for the majority of the population than accessible designs for reasons other than capability requirements, as discussed in Section 3.4. Additionally, the higher capability requirements of universal designs usually make them cheaper to create than accessible designs.
Table 4.1: Summary of the grip strength requirements and accommodation levels for each design type.

<table>
<thead>
<tr>
<th>Design Type</th>
<th>Grip Strength (kgf)</th>
<th>Overall Accommodation</th>
<th>Accommodation of the People with the Bottom 5% Capabilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typical</td>
<td>22.29</td>
<td>95.00%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Accessible</td>
<td>12.42</td>
<td>99.91%</td>
<td>98.21%</td>
</tr>
<tr>
<td>Universal</td>
<td>14.35</td>
<td>99.84%</td>
<td>96.86%</td>
</tr>
</tbody>
</table>
The goal of this research was to provide designers with a methodology for establishing design capability requirements so that they could increase the universality of universal designs. To accomplish this task, the methodology proposed quantifying and analyzing the range of capabilities that existed within a population. A weighting procedure was presented that emphasized weaker capabilities when creating both accessible and universal designs.

A modification to the Seven Principles of Universal Design was also presented with the intention of increasing design universality. Prior to this modification, it was possible to create non-universal designs that adhered to the Seven Principles of Universal Design. However, the newly added principle, Attractive Appearance, will ensure that designers focus on a universal appearance in addition to usability.

A grip strength example was presented to demonstrate how capability requirements change depending upon the design type. The accessible design had the lowest capability requirements because of the emphasis accessible designs place on individuals with low capabilities. Universal designs, however, consider all capabilities equally.

The proposed methods for calculating capability requirements must be used alongside the modified Principles of Universal Design when creating universal designs. The use of the principles is necessary because capability requirements alone do not define a universal design. The flowchart shown in Figure 5.1 summarizes how capability requirements and adherence to the Principles of Universal Design classifies the type of design being created.
5.1 Primary contributions

The proposed methods increase design universality by giving designers a specific capability level to which they can design. By analyzing capability data of their target populations, designers ensure that they design for the entire ranges of capabilities that exist within that population, regardless of disabilities. Since each individual’s capability is equally considered in a universal design, it prevents the creation of designs that are only usable by people without disabilities.

An additional benefit of using capability data for design is that the data prevent excessive accommodations, which could be rather costly. For instance, a designer could attempt to design the front door of a house such that every single person in a population...
would have the strength or capability necessary to open it. However, this design would
likely come at an exorbitant cost. The door would either be very fragile, or the materials
required to make the door would be very expensive. Also, the door would likely provide
very little protection from weather and outdoor noises. However, if the designer instead
chose to use the proposed methods to identify the capability level needed for a universal
door, it would be possible to create the door at a reasonable cost while still making it
usable for nearly everyone in the population. Alternatively, the proposed methods may
inspire the designer to create a new way to open the door, such as a button or motion
sensor, in an attempt to design for all.

The proposed work will also benefit designers creating universal designs by ensuring
that they focus on the appearances of their designs. The newly added universal design
principle focuses on design aesthetics because of the major role appearance plays in
consumer product selection. Norman (2004) argues that many products are bought solely
based on their appearances, and products that perform well may still fail if users dislike
how they look. Additionally, he states that users perform better when using products that
they find aesthetically pleasing. Therefore, the universality of potential universal designs
could be reduced if their appearances do not appeal to a wide variety of users. The
Attractive Appearance principle emphasizes aesthetics so that designers do not overlook
this important aspect of design.

5.2 Required tools

It is important to review the tools that are necessary to implement the proposed
methodology. The most important tool needed is a relevant capability database, which
may, unfortunately, be the hardest tool to find or access. In instances where a capability
database is not readily available, it may be necessary for the designer to create a new
capability database by sampling the target population, which could be costly and
time-consuming. The capability data need to pertain to the design that is being created.
For example, a leg strength database would be needed to design a foot pedal, and a
finger strength database would be needed to design a switch. Another important feature
of this capability database is that it must also contain some measure of anthropometry. This measure of anthropometry, stature for instance, is needed to develop the regression model relating anthropometry to capability. Based on this regression model, capability values can then be predicted for the individuals in the NHANES database. The NHANES database, in addition to the predicted capability values, can then be used to create typical, accessible, and universal designs.

In addition to capability databases and the NHANES database, a designer also needs access to a computational software program. For the purposes of this work, R statistical software (available for free at http://www.r-project.org/) was used to perform the necessary calculations; however, MATLAB or other tools could have also been used for computational purposes. The software must be capable of calculating weighted percentiles as well as creating weighted histograms.

5.3 Limitations and future work

Although the work thus far has mostly focused on the benefits of universal design, there are times when universal design is inappropriate or unnecessary. For example, it would not be beneficial to design a car such that individuals with extreme vision disabilities could use it. Therefore, a designer must ensure that making a design universal will benefit the potential users before deciding to take on this task. He or she must also ensure that improving a design for people with a particular disability does not make it harder for people with different disabilities to use the design (Newell and Gregor, 2000).

Shneiderman (1999) also warns of some of the potential dangers of universal design. For example, some designers attempting to create a design that benefits everyone essentially create an overly simplified design that does not benefit most people. In addition, some designers end up restricting the abilities of individuals without disabilities in an attempt to design for the capabilities of individuals with disabilities. These problems can generally be avoided as long as the designer is aware of them and strives to circumvent them; however, the fact they are possible still poses a problem that is not directly addressed by the Principles of Universal Design.
Although Goodman-Deane et al. (2010) find that designers often prefer non-systematic tools and methods, one of the main limitations of the modified Principles of Universal Design is that they are mostly qualitative in nature. The capability requirements established in the methodology can be used in combination with the Principles of Universal Design to give designers a more quantitative approach to creating and assessing universal designs. Additionally, the principles describe what a universal design is and should do, but they do not provide detailed methods to obtain these measures. Designers with existing, non-universal products would have a difficult time using only the Principles of Universal Design to make their products universal. A design strategy is needed to walk designers through the universal design creation process so that they not only know what a universal design is, but they also have a detailed plan to produce one.


design principles. Available from: http://www.design.ncsu.edu/cud/about_ud/udprincipleshtmlformat.html#top.


