Design of Customized Independent Living Environment for Individuals with Mobility Issues

by

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Abstract

Since ancient times, the groups of people with disabilities cannot be ignored, and wars around the world resulting in many amputations in army veterans and civilians have brought disability issues to the world consciousness. Up to now, through the efforts of the people with disabilities and relevant organizations, the rights and interests of the disabled group have been well protected and developed, but even so, the inconvenience of the people with disability in daily life has not been solved. However, while ADA standards for accessible design in 2010 set requirements for public environments and facilities, there are no standard requirements for private living space and furniture. Therefore, the lack of disability-focused rational design of interior and furniture prevents disabled individuals from living barrier-free and independently even at home.

Thus, the purpose of this thesis is to develop a design tool through learning, understanding, and analyzing ergonomics, furniture design, and interior design for users and designers to design independent living environments that can accommodate both the physical and psychological needs of those with mobility issues.

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Chapter 1. Introduction

1.1 Problem Statement

Due to the existing designs of residential spaces that are typically created for able-bodied people, people with mobility impairments face many challenges in living independently. Moreover, a growing aging population has increased the prevalence of mobility issues. In a 2023 CDC report, 27 percent of adults in the United States live with a disability and 12.1 percent of people have varying degrees of mobility disabilities (2023).

At present, many residential spaces cannot meet the specific needs of those people with mobility issues, making daily living and working difficult and potentially hazardous. There is a tendency to only follow basic requirements of accessibility guidelines rather than considering the diversity and uniqueness of individuals with different mobility impairments. For example, even among wheelchair users, there can be different problems of mobility and use of different types of wheelchairs, such as manual or electric. Therefore, people with mobility issues often face difficulties or struggles in daily life with furniture and spaces that do not meet their requirements and needs, which makes it impossible for them to live alone even when they have the ability to live independently.

In order to solve this problem, designers need a design guide that combines the existing principles, modular design, and user-centered consideration to create a living environment that is not only fully accessible, but also promotes independence, comfort, and quality of life.

1.2 Need for Study

However, with growing awareness of the importance of accessibility and inclusivity in design, there are gaps in designing living spaces for people with disabilities, especially when it comes to furniture design. Most of the standards or principles pay more attention to making public spaces and facilities accessible, but there is no specific guideline to meet the personal interior space design and furniture of the independent living needs of people with disabilities. Independent living space is not only about accessibility but also about how to use furniture and other home facilities independently and comfortably. Therefore, designers need to have a sufficient understanding of anthropometrics and mobility aids. Also, learning and applying the Americans with Disabilities Act (ADA) standards is the most basic but necessary requirement.

Furthermore, modular design can be very helpful when designing furniture and interior spaces for people with disabilities. The modular furniture design can provide a more flexible living environment. However, there is not a guideline for modular furniture design to provide designers with suggestions, in this study will also do some research and give designers some advices.

Therefore, this thesis focuses on furniture design and space planning for people with mobility issues and combines modular design with a design tool that follows the requirement of ADA standards to help designers create more independent and comfortable living environment.

1.3 Objective of Study

- To identify the needs, challenges, and preferences of people with mobility issues in their daily life.
- To identify and analyze the obstacles and difficulties that people with mobility issue face in independent living spaces.

- To research and learn the field of anthropometrics, especially focusing on the dates of people with mobility issues and apply this information to the design tool.
- To evaluate and learn existing design principles, standards, furniture design and interior design.
- To research on modular design and explain the benefits for people with mobility issues lives independently.
- To develop the design tools (guideline), analyzing and incorporating findings from the above objectives. This tool will guide designers in creating independent, comfortable living spaces for people with mobility issues.
- To use the design guide creating an independent living space for people with mobility issues that demonstrates how to apply the guidelines and the effectiveness of the guidelines.

1.4 Definition of Terms

- **ADA Standards:** American Disabilities Act (ADA) standards stipulate the basic requirements of public spaces or facilities accessible and available for people with disabilities (*2010 ADA Standards for Accessible Design*, 2010).
- **CDC:** CDC is the nation's leading science-based, data-driven, service organization that protects the public's health (2023).
- **Anthropometry:** Anthropometry is the science that defines physical measures of a person’s size, form, and functional capacities (*CDC, 2022*).

1.5 Assumption

- For the purposes of this study, it is assumed that all research, approaches, methods, and data referenced are correct and valid.

- All designers will use the design tools in the intended way.
- It is assumed that reasonable and thoughtful design of furniture and living environment can significantly contribute the ability of people with mobility issues to live independently.
- This study assumes that participants with mobility issues have the ability to live independently and express a desire to live independently. The purpose of the study is to promote independent living, and its effectiveness can only be accurately assessed if participants are both competent and interested in independent living.

1.6 Scopes and Limits

Firstly, the scope of this study is mainly focused on adults with mobility issues who still have the ability and desire to live independently. Although there are many different types of disabilities, this thesis only focuses on this specific focus in order to develop a more targeted design approach. While many factors can contribute to mobility problems and limitations in independent living, this study limits its focus to physical conditions. Psychological or mental conditions that could affect mobility or independent living, such as autism or depression, are outside the scope of this study.

Secondly, while household appliances are integral parts of daily living life, such as microwaves, ovens, televisions, etc., this study does not encompass the design or modification of such appliances. Similarly, the research is centered on the design of living spaces and furniture, with other aspects of independent living (such as community support, public facilities, etc.) are not included in this study.

Finally, this paper primarily focuses on residential spaces within the United States. The mentioned regulations, requirements, standards, and laws are applicable only to the U.S region.

1.7 Procedure and Methodology

Procedure 1: Research and study people with mobility issues and find what kind of challenges they may face.

- To research about mobility disabilities in library and online.
- To analyze and discover the problems and needs of people with mobility issues.

Procedure 2: To analyze and learn existing design principles, standards, and requirements.

- To learn the 2010 ADA standards for accessible design.
- **Procedure 3: To study human ergonomics & dimensions of mobility aids.**
- Learn and collect ergonomic data and knowledge through books and online research.
- Summarize and analyze the collected data and knowledge that can be used in the guideline.

Procedure 4: Research on modular design.

- Learn modular design through books and online research.
- Combine researched knowledge with furniture and interior design.

Procedure 5: Develop the guideline for designers to learn and reference for design of independent living environment for people with mobility issues.

1.9 Anticipated Outcomes

The primary outcome of this study is to develop a design guide integrating knowledge from different fields to help designers create a convenient and comfortable living environment for people with mobility issues so that they can live independently. Moreover, this design

approach can be used to evaluate existing products and living environments to assist designers in modifying and redesigning. Through this design approach, this study hopes that individuals with mobility issues can have more convenient living environments and furniture.

Chapter 2. Literature Review

This literature review focuses on the survey and analysis of academic writings, existing standards, and principles related to the design of independent living environments for individuals with mobility issues.

During the research on this topic, the authors realized that independent living is not only about accessibility but also about comfort, safety, and user control over their daily lives. Some people with disabilities who have the desire and ability to live independently face many obstacles and even dangers in their daily lives due to unreasonable design.

Therefore, in order to achieve a better living environment for the target group to live independently, this chapter will discuss the concept of independent living, type of mobility issues, existing design standards and principles, anthropometric research, and different mobility devices. This literature review will also talk about modular design, and how modular design can help target users improve independence.

Through studying and analyzing of the above aspects, this literature review lays the foundation for the development of a design guide that truly supports and improves the independent living of people with mobility issues.

2.1 Independent Living

“Independent Living is a philosophy and a movement of people with disabilities who work for self-determination, equal opportunities and self-respect.” - Dr. Adolf D. Ratzka, Presentation at the conference "Our Common World", 1997

2.1.1 The Concept of Independent Living

The concept of "Independent Living" originally came from the disability rights movement that began in the 1960s. The philosophy of the Independent Living movement is based on that people with disabilities should be treated as citizens first, followed by the other aspects of their specific needs as people with disabilities (Ratzka, 1997). As citizens, they are born with the equal participation, freedom, and control over their daily life (Ratzka, 2005). This philosophy emerged to promote that people with disabilities should enjoy the same social rights and opportunities as those people without disabilities.

Dr. Adolf D. Ratzka (1997) said in the speech "Our Common World":

> "Independent Living does not mean that we want to do everything by ourselves and do not need anybody or that we want to live in isolation. Independent Living means that we demand the same choices and control in our everyday lives that our non-disabled brothers and sisters, neighbors and friends take for granted".

Thus, eliminating obstacles in daily life for people with disabilities is essential for achieving social equality.

This research realized that the concept of independent living is very broad and complex, which may cover daily travel, social participation, work, and other aspects. In this study, "Independent Living" specifically refers to the ability to carry out daily activities independently

without depending on others, and to encourage people to enjoy the rights and opportunities that they are entitled to.

2.1.2 The Significance of Independent living for People with Disability

The progress and development of life make many people take everything for granted. Freedom of life, equal treatment, and optional beliefs are the powers given to every citizen (Lawlor & Thomas, 2008). However, for people with disabilities, it doesn't seem to be that simple. In 1964, the Civil Rights Act in the United States established the principle that all citizens enjoy equal rights. Although the Act did not address the rights of people with disabilities, it set a precedent for anti-discrimination legislation. The Americans with Disabilities Act, passed in 1990, this Act emphasized the prohibition of discrimination against people with disabilities and required equal treatment for them in public facilities, employment, and services (Americans with Disabilities Act of 1990). Those regulations provided the legal foundation for promoting an independent living environment for people with disabilities.

In recent years, more attention has been paid to the concept of designing for all, encouraging the elimination of discrimination and the promotion of equality (Smith & Preiser, 2011). However, it has to be admitted that the rights and interests of disabled are often not protected as they should be. Some people even absurdly claim that it is a waste of national resources to spend a lot of money to make every building wheelchair accessible. They said it would be much easier and more cost-effective to hire two able-bodied people to carry the occasional wheelchair user up the stairs (Imrie & Hall, 2001, p. 5). This sounds very extreme and outrageous, but the discrimination and disrespect for minority groups is real. Everyone should be aware that people with disabilities are entitled to the same rights and freedoms as other citizens in their daily lives. For this purpose, society needs to eliminate the infrastructure, system and

attitude barriers to the independent life of the people with disability as much as possible *(Disabled World, 2014).* Therefore, supporting independent living for people with disabilities is a crucial step towards a more inclusive and equal society, so that everyone can equally participate in social, economic, and cultural activities.

On the other hand, for people with disabilities, independent living allows them to freely choose and control the life they want. This is an important expression of respect for the dignity and autonomy of every person. It is a right to be responsible for one's own choices and to learn and grow from making mistakes, just like everyone else (Pineda & Corburn, 2020).

Living independently not only means eliminating physical barriers in the living environment, but also about social attitudes and stereotypes that marginalize people with disabilities.

2.2 Focus on Mobility Issues

In the above section, the concept and importance of independent living were discussed. This section mainly discusses the research object - people with mobility issues. It will involve understanding what mobility issues are, why this group was chosen as the subject of this study, and how this group is affected in their quest for independent living.

2.2.1 Understanding Mobility Issues

In order to carry out the following research more effectively, studying and understanding the target group is necessary. Mobility issues is a broad term that refers to any condition that affects a person's ability to move. Mobility issues can be temporary (such as due to an injury), permanent (such as amputation), or progressive (aging) *(Accessibility.Com, n.d.; Disabled World, 2014b*). Below are definitions of mobility impairment by some related organizations:

The ACCESS Project (n.d.) identified that:

> Mobility impairment refers to the inability of a person to use one or more of his/her extremities, or a lack of strength to walk, grasp, or lift objects. The use of a wheelchair, crutches, or a walker may be utilized to aid in mobility. Mobility impairment may be caused by a number of factors, such as disease, an accident, or a congenital disorder and may be the result from neuro-muscular and orthopedic impairments.

Disabled-World (2014) defined that:

> Mobility impairment is defined as a category of disability that includes people with varying types of physical disabilities. This type of disability includes upper or lower limb loss or disability, manual dexterity, and disability in co-ordination with different organs of the body. Disability in mobility can either be a congenital or acquired with age problem. This problem could also be the consequence of disease. People who have a broken skeletal structure also fall into this category of disability. Persons with physical impairment disabilities often use assistive devices or mobility aids such as crutches, canes, wheelchairs, and artificial limbs to obtain mobility.

These statements allow a recognition that the causes of mobility issues are broad, which come with varying degrees of difficulty in mobility. In order to gain better understanding of the variety and complexity of this category, it is necessary to study the different types of mobility issues.

2.2.2 Types of Mobility Issues

This section talks about common reasons that cause mobility problems. These are divided into four categories: orthopedic/musculoskeletal disorders, neurological disorders, injuries and age-related (Kaye et al., 2000; Disabled-World, 2014b). Each type may create unique challenges and specific requirements for independent living. In addition, different types and degrees of mobility issues can lead people to use different types of mobility aids.

Orthopedic/Musculoskeletal Disorders: Orthopedic/Musculoskeletal disorders are the leading cause of disability worldwide (World Health Organization, 2022). According to the Global Burden of Disease Study 2019, there are approximately 1.71 billion people with musculoskeletal conditions globally (Cieza et al., 2020). These disorders include over 150 different conditions that may affect the locomotor system, such as arthritis, osteoporosis, and muscle atrophy, which can limit mobility and dexterity (World Health Organization, 2022). These conditions often come with pain and limited movement, leading to decreased independence and quality of life.

Neurological Disorders: Having difficulty in walking is a major feature of neurological disorders, and the loss of mobility is a primary concern in daily life activities for those people (Pearson et al., 2004). Neurological disorders can result in difficulty with movement and balance. For example, strokes may affect muscle weakness, paralysis or stiffness and those effects can make it hard to move or walk (Stroke Association, 2017). Some people who have had a stroke need assistive devices to help them to walk. This condition brings significant challenges to living an independent life.

Injuries: Injuries can lead to temporary or permanent mobility issues. These may include fractures or amputations, and each of them can have different effects on mobility *(Disabled-*

World, 2014). For example, a fracture may cause temporary mobility issues, and people might need to rely on mobility aids, such as crutches or wheelchairs in this term. During this period, they may face new challenges in their daily life due to limited mobility. In addition, accidents or injuries can also pose psychological problems. Individuals may struggle to accept changes in their physical condition, leading to anxiety, depression, or even post-traumatic stress disorder (PTSD) (Bombardier et al., 2012). Although mental health is not within the scope of this study, these psychological problems will aggravate the challenges of independent living, and designers should take mental health into consideration.

Age-Related: Aging is an inevitable process. With the increase of age, various physical abilities decline, leading to mobility issues (Fried & Guralnik, 1997). Decreased physical strength and flexibility may make it difficult for old people to comfortably live in homes that were suitable when they were younger. Designers need to consider the possible effects of aging as appropriate. Because aging and mobility problems are closely related and important topics, more studies about aging will follow in the coming section.

Studying different types of mobility issues and their causes can help in better understanding the specific challenges and needs of different people facing in independent living. However, it is important to know that not all people with mobility issues can live independently. There are some conditions or limitations that require additional assistance or support in daily life so that these individuals cannot live alone.

2.2.3 Aging and Mobility

According to the report from World Health Organization (2015), between 2015 and 2050, the number of people aged 60 years or older will rise from 900 million to 2 billion. Figure 1 and Figure 2 show the distribution of the world's population over 60 years old in 2015 and the

projection for 2025 (World Health Organization, 2015). Because of this demographic change, design requires more attention to the mobility challenges that may face older people. Meanwhile, mobility problems are becoming more and more common among the elderly. The research shows about 35% of the 70-year-olds and most of the 85-year-olds have mobility issues to varying degrees (Freiberger et al., 2020). The causes of mobility issues that are mentioned above due to orthopedic/musculoskeletal disorders or neurological disorders can be age-related, such as arthritis, Parkinson's and some cardiovascular diseases. These kind of diseases often lead to restricted mobility and difficulties in daily life (Kaye et al., 2000).

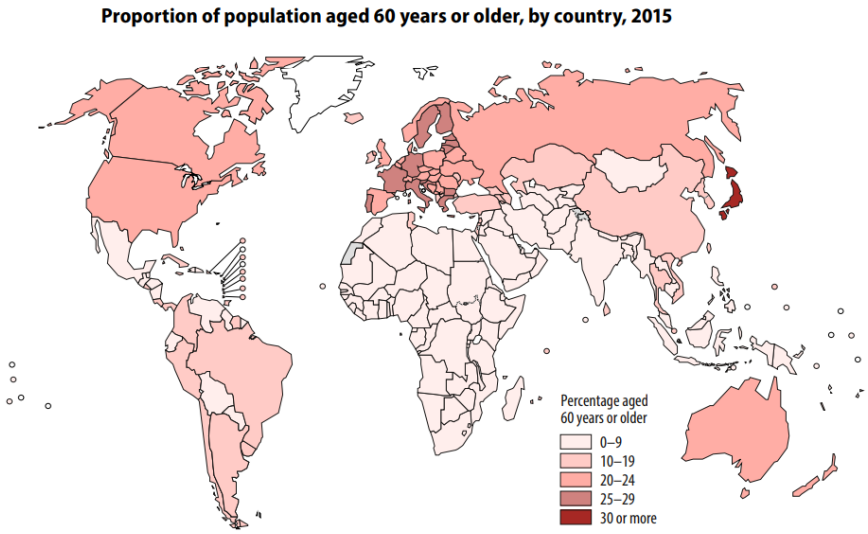


Figure 1 Proportion of Population Aged 60 Years Old, by Country, 2015 (World Health Organization, 2015)

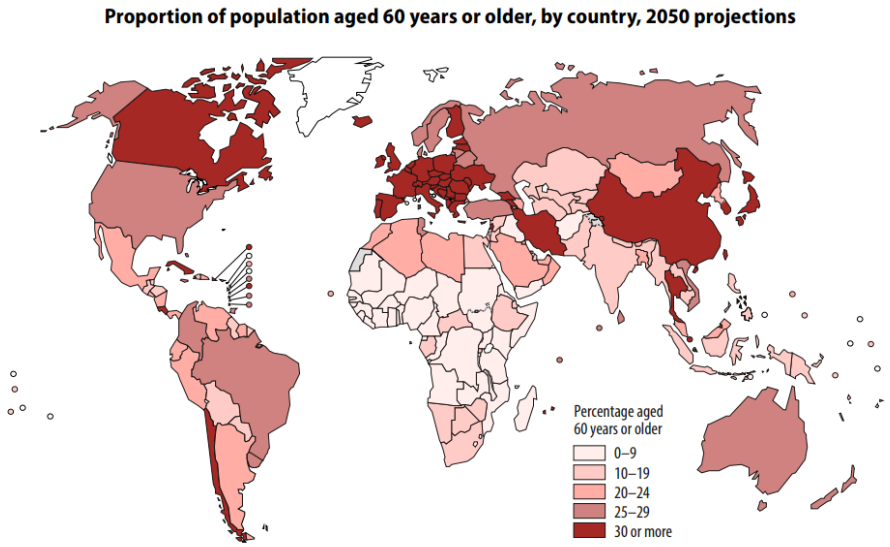


Figure 2 Proportion of Population Aged 60 Years Old, by Country, 2050 projections (World Health Organization, 2015)

Due to the trend of aging populations, the number of elderly people living alone is also increasing. In some European countries, over 40 percent of women aged over 65 choose to live alone (Ireland, 2007). Also, many elderly people said they preferred to live alone rather than with their family (World Health Organization, 2015). However, this choice poses some difficulties, since growing old results in a decrease in physical ability, susceptibility, and reduced mobility. These factors lead older adults to have difficulty completing everyday household works or face difficulties in their daily lives without others' help. Therefore, understanding the unique needs and limitations of seniors is critical when designing living spaces for them.

2.2.4 Why Choose People with Mobility Issues as the Focus of Study

Mobility issues are bothering many people around the world. According to the CDC (2019) report, mobility is the most common type of disability, affecting one in seven adults in the US. According to U.S. disability statistics, there are 17.2 million adults over the age of 18

that have difficulty walking *(Disabled-World, 2014).* And as the global population aging problem intensifies, more and more people will be troubled by mobility issues.

On the other hand, people with mobility problems may spend more time at home because their motion range is limited by muscle stiffness, spasms, or loss of muscle strength that may result from disease (Disabled-World, 2014). As discussed above, many different reasons can result in mobility issues, so the specific needs of this group of people for independent living are diverse. In order to ensure that everyone can live with a living space that meets their special needs, a design tool is needed to help designers develop more inclusive designs and environments.

The author believes that improving the living environment for each disabled person is a pursuit of social equality. This thesis insists that all people have the right to live independently and participate in social activities on an equal footing.

2.3 Related Concepts and Design Standards

When discussing the design of independent living spaces for people with mobility issues, several design concepts are often involved: accessible design, universal design, and inclusive design. These design concepts are often confused but each one has a different pertinence and purpose. In addition, there is a design idea for elderly people related to interior design and remodeling, which is "Aging in Place". It is necessary to understand and study because of the close relationship between aging and mobility issues. In this section, the ADA Standards for Accessible Design will also be discussed. As a guideline with legal effect, these standards provide essential baseline requirements for creating an accessible environment.

2.3.1 Accessible Design

Accessible design is often used in products or environments specifically considered for people with disabilities, meaning that products, services, and facilities can be accessed and used by people with disabilities (Pirkl, 1994). Accessible Design was initially used in architecture and planning, specifically referring to "Accessibility", which most countries define through laws (Iwarsson & Ståhl, 2003, p. 58). In the Swedish Legislation on Planning and Building, an explanation and definition of accessibility is provided: "To allow any individual, in spite of impairments, to get into and out of any building independently" (1987). While accessible design has increased the accessibility of buildings and products that were originally difficult to enter and approach, the philosophy of accessible design is based on the existence of two different groups of people: those with disabilities and those without (Smith & Preiser, 2011). This can lead to stigmatization and marginalization. In contrast, "universal design" and "inclusive design" are more based on a principle of the “one” group (Iwarsson & Ståhl, 2003).

2.3.2 Universal Design

Universal design is a concept that creates environments and products that everyone can use, no matter their age, ability, or disability (Iwarsson & Ståhl, 2003). This concept is different from accessible design, which is often used in designs to meet the needs of people with disabilities (2003). The term universal design was created by architect Ronald Mace who defined it 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" (Smith & Preiser, 2011, p. 13). The purpose of universal design is to simplify everyone's life by making products, communications, and the environment easier to use by as many people as possible without extra

cost (Nussbaumer, 2012). In addition, universal design has seven design principles that were established by the Center for Universal Design (CUD) in 1997:

1. **Equitable Use:** The design is useful and marketable to people with diverse abilities.
2. **Flexibility in Use:** The design accommodates a wide range of individual preferences and abilities.
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.
4. **Perceptible Information:** The design communicates necessary information effectively to the user, regardless of ambient conditions or the user's sensory abilities.
5. **Tolerance for Error:** The design minimizes hazards and the adverse consequences of accidental or unintended actions.
6. **Low Physical Effort:** The design can be used efficiently and comfortably and with a minimum of fatigue.
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.

(See Figure 3 for more information)

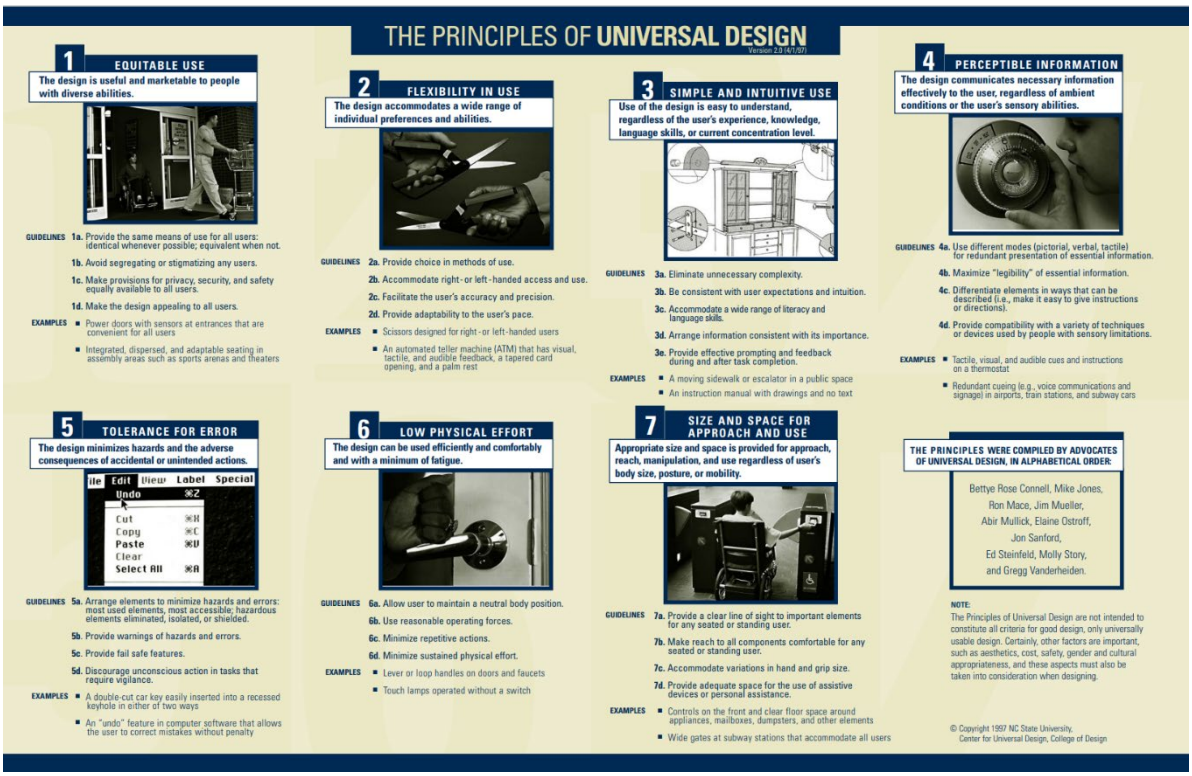


Figure 3 The Principles of Universal Design (CUD, n.d.)

Of course, designing a product that everyone can use is not feasible. A more realistic way is to design for the broadest range of people who are most likely to use the product or environment (Nussbaumer, 2012, p. 29). Therefore, the concept of "inclusive design" has emerged.

2.3.3 Inclusive Design

Inclusive design is similar to universal design, but it has some unique distinctions. The British Standards Institute defines inclusive design as "the design of mainstream products and/or services that are accessible to, and usable by, as many people as reasonably possible ... without the need for special adaptation or specialised design" (BSI, 2005). Inclusive design recognizes that one design is not possible to satisfy everyone. Instead, it aims to provide personalized solutions with multiple designs to balance everyone's needs (Inclusion-by-Design). “Design for Everyone” of inclusive design considers the variability of all people. It's a flexible and

innovative design approach. The Commission for Architecture and the Built Environment (CABE) in 2008 developed 5 principles of Inclusive Design:

1. Inclusive design places people at the heart of the design process.
2. Inclusive design acknowledges diversity and difference.
3. Inclusive design offers choice where a single design solution cannot accommodate all users.
4. Inclusive design provides flexibility in use.
5. Inclusive design provides buildings and environments that are convenient and enjoyable to use for everyone.

By following these principles, design development will be inclusive, responsive, flexible, convenient, accommodating for all people, welcoming with no disabling barriers, and realistic (For more details, refer to figure 4).

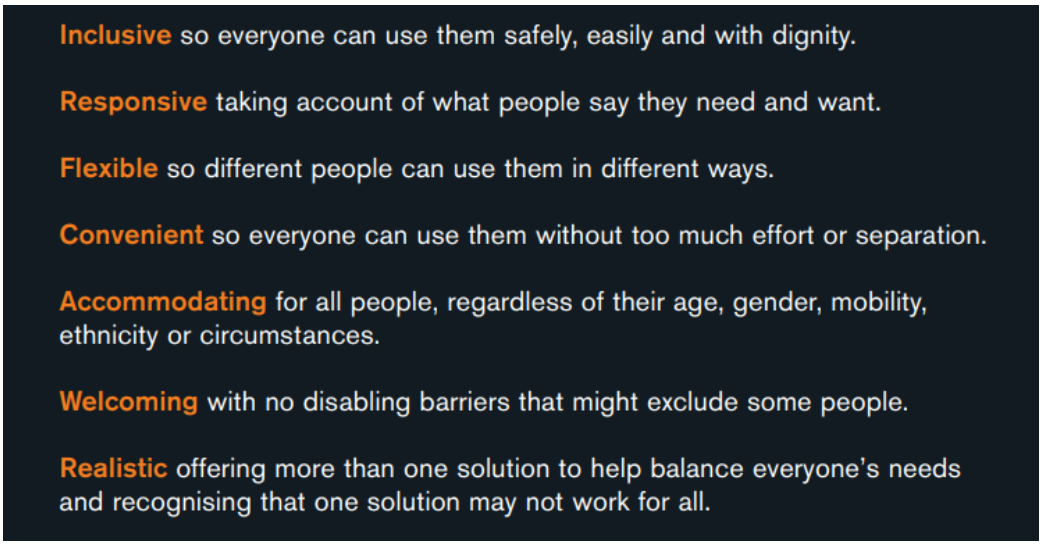


Figure 4 Seven keys of Inclusive Design (The Principles of Inclusive Design)

2.3.4 Aging in Place

"Aging in place" is a concept related to sustainable design. The American Association of Retired Persons (AARP) defines aging in place as “a concept in which individuals continue to live in their long-term homes and communities where they feel safe and comfortable and are able to maintain their independence for as long as possible, regardless of age, income level, or physical ability” (Nussbaumer, 2012, p. 127). The purpose is to assist older adults in living comfortably and independently in familiar surroundings.

Most existing homes were not designed with the varying needs of different ages and abilities, let alone considering changes that may come with aging (Nussbaumer, 2012). Table 1, taken from the research from the American Housing Survey (AHS), lists 22 accessibility features in housing units and whether those features were used.

Accessibility level	Prevalence
Level 1: Potentially Modifiable. The home has some essential structure features for accessibility, but would not be accessible without further modifications. This includes stepless entry from the exterior, bathroom and bedroom on the entry level or presence of elevator in the unit.	33.3% of all housing units 44.2% of housing units with a resident wheelchair user
Level 2: Livable for individuals with moderate mobility difficulties. A person with moderate mobility difficulties can live in the home. This includes all the elements in level 1 plus no steps between rooms or rails/grab bars along all steps and an accessible bathroom with grab bars.	3.8% of all housing units 12.4% of housing units with a resident wheelchair user
Level 3: Wheelchair accessible. The home has a minimum level of accessibility so that a wheelchair user can live in the home and prepare his or her own meals. This includes all the elements in levels 1 and 2, but removes the possibility of any steps between rooms, even if grab bars are present, and adds door handles and sink handles/levers	0.15% of all housing units 0.73% of housing units with a resident wheelchair user

Figure 5 Accessibility and Prevalence (Bo'sher et al., 2015)

The research shows that most homes do not provide accessibility for all people who have mobility difficulties. Therefore, as aging leads to mobility issues, homes need to be changed. Rather than moving to a new environment, renovating and modifying the original homes may be better for elderly people, because a familiar environment can reduce the stress brought on by aging (Nussbaumer, 2012; World Health Organization, 2015).

2.3.5 ADA Standards for Accessible Design

The Americans with Disabilities Act (ADA), enacted into law in 1990, prohibits discrimination against people with disabilities in all areas of public life, including jobs, school, transportation, and all public and private places that are open to the general public *(ADA National Network)*. After revision in 2008 and 2010, the complete standards were established for accessibility to ensure that all public building and facilities should be accessible to people with disabilities.

The ADA standards for accessible design provide information (size, dimension and requirements) for various design features including but not limited to ramp dimensions, entrance size, and restroom layout. While most private residential buildings do not have to conform to ADA standards (2010 ADA Standards for Accessible Design, 2010), it is necessary to know those principles and guidelines that can be invaluable in designing private residences for people with mobility issues or anyone looking for a more inclusive environment.

However, the ADA standards are just a foundation for building accessibility; they are minimum requirements. So, designers need to go beyond these standards to provide their users with a more comfortable and specific living space.

2.3.6 Limitations and Directions

While progress has been made in accessible, universal, and inclusive design, and also legislative support such as the ADA standards exists, there are still gaps, and rooms can be improved in creating independent living space for people with mobility issues, especially in private residences, since there are no legally standards to constrain and regulate it.

Through the study of related design concepts, it is found that most design standards and principles still use the "one size fits all" approach. Even though inclusive design has claimed the idea that one design cannot meet the needs for all people, living space design still does not fully cater to the people with special needs and experiences such as individual with different types of mobility issues.

This study not only emphasizes "accessibility" at home, but also enables users to use all house facilities easily and independently. Therefore, the study aims to develop a design guide to address these gaps and limitations through the user-centered idea and hopes to go beyond

existing standards and principles so that the guideline results in design that is not only accessible and inclusive, but also tailored and personal.

2.4 Mobility Device

Assistive Devices such as mobility aids are an effective tool to reduce the effects of mobility issues for people, such as wheelchairs, scooters, canes, crutches, etc. to improve walking and independence ability. In the United States, more than 6.8 million residents use mobility devices to help them move (Kaye et al., 2000).

2.4.1 Types of Mobility Aids

People with disabilities have the right to choose the mobility device that best suits their needs. For example, some people like to choose a manual wheelchair instead of a power wheelchair because it helps them maintain upper body strength, while some people with the ability to stand may like to choose manually powered mobility aids, such as crutches or cane (ADA, 2023). This article divides mobility devices into three categories: wheelchairs, manually powered aids and others.

Manually Powered Aids: The most common types of manual mobility aids are canes, crutches, and walkers. Canes are designed to provide balance support for standing and walking (Haddas et al., 2020) such as support for elderly people with aging joints. In the United States, an estimated 1 in 10 adults over the age of 65 use a cane. Canes help the user transfer the load from the lower body to the upper body but hands and wrists receive more pressure at same time (Medical News Today, 2017). There are also many types of canes, such as t-shaped, offset, crook, swan neck, etc. (Arefin et al., 2020). Cane users can often use canes for short-distance stair climbing.

Crutches help transfer weight from the legs to the upper body, they can be used alone or in pairs, and they are often used by people who cannot support their body on their legs (short-term injury or permanent disability) (Physiopedia contributors, 2023). There are also many types of crutches; the common ones are axillary or underarm crutches, forearm/elbow crutches and gutter crunches (Figure 6). The overall height and handle height of crutches are usually adjustable to suit each patient's needs.

Walkers are walking aids that have four points of contact with the ground. It provides a wider base of support than a cane, therefore it is used more for stabilizing balance and for people with poor mobility or lower extremity injuries (Arefin et al., 2020). The user's choice of walkers often depends on the location of use, the activity, and how much support they need (Hall et al., 1990). Compared with canes and crutches, walkers may need more space for activities, and the specific range needs to be judged according to the particular aids used by the user.

Figure 6 Types of Crutches (Physiopedia contributors, 2023)

Wheelchairs: Wheelchairs are for people who should not be putting weight on their lower body or people who are not able to walk *(Medical News Today, 2017).* They may be better to use than manual mobility aids for people with disabilities that need to travel long distances. The types of wheelchairs can be roughly divided into manual wheelchairs and powered wheelchairs. There are various types of wheelchairs, and different wheelchairs will have different dimensions due to different types or versions (Panero & Zelnik, 1979), such as overall height, width, seat height, etc., so the designer should measure the user's wheelchair individually.

Others device: In addition to the two most used aids, there are also scooters and prosthetic devices, etc. Because there are many types and styles of such aids, the space design needs to be considered, measured, and designed according to the specific device type, size, and usage of the user.

2.4.2 Mobility Device Statistics

There are some reports about the use of mobile devices in the United States. To effectively use mobile devices, the environment in which they are used must be accessible. Knowing this information can help designers better understand users and their devices. The following information and numbers are from the National Institute on Disability Rehabilitation Research U.S. Department of Education (Kaye et al., 2000).

- Osteoarthritis is by far the most prevalent condition associated with mobility device use, affecting 1.2 million mobility device users as the primary cause of disability.
- Stroke and osteoarthritis are the two most prevalent primary conditions among wheelchair and scooter users.
- Figure 7 shows the proportion of the population using mobility devices. It can be seen from the figure that walking sticks are the most widely used mobile devices, accounting for 70% of mobile device users. Among wheelchair users, 90% choose to use manual wheelchairs (p. 7)

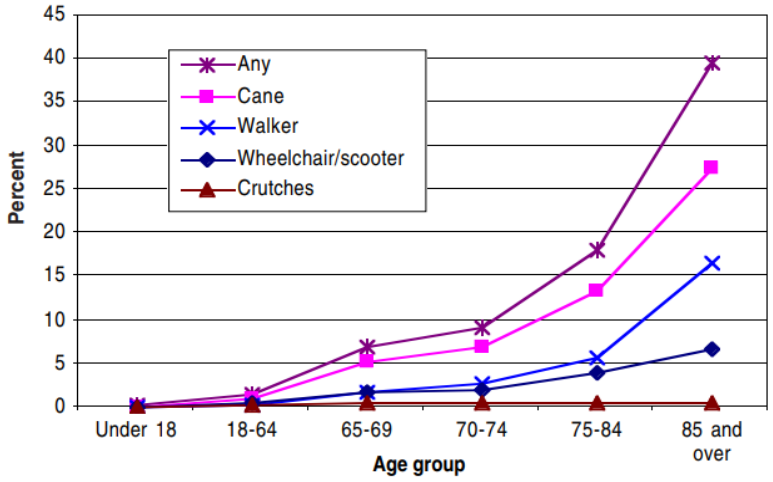


Figure 7 Proportion of population using mobility devices, by age and device (2000, p. 7)

- As shown in Figure 8, device users are restricted in many ways, whether they are unable to perform a major activity, limited in amount or kind of major activity, or limited only in some other activity. More than 43.2 percent of mobility device users are unable to perform a major activity, and more than two-thirds of mobility device users have some degree of limitation in the major activity. Among them, scooter and wheelchair users are the most likely to have an activity limitation (p. 17).
- Figure 9 is a report of the proportion of mobility device users and non-users with home accessibility difficulties. The figure shows that even users of mobile devices at home often encounter various problems. Most wheelchair users report difficulty getting in and out of their home. In fact, forty-seven percent of wheelchair users and thirty-two percent of mobile device users had difficulty reaching or opening cupboards; thirty-five percent of wheelchair users and nineteen percent of mobile device users had difficulty going to the toilet (p. 32).

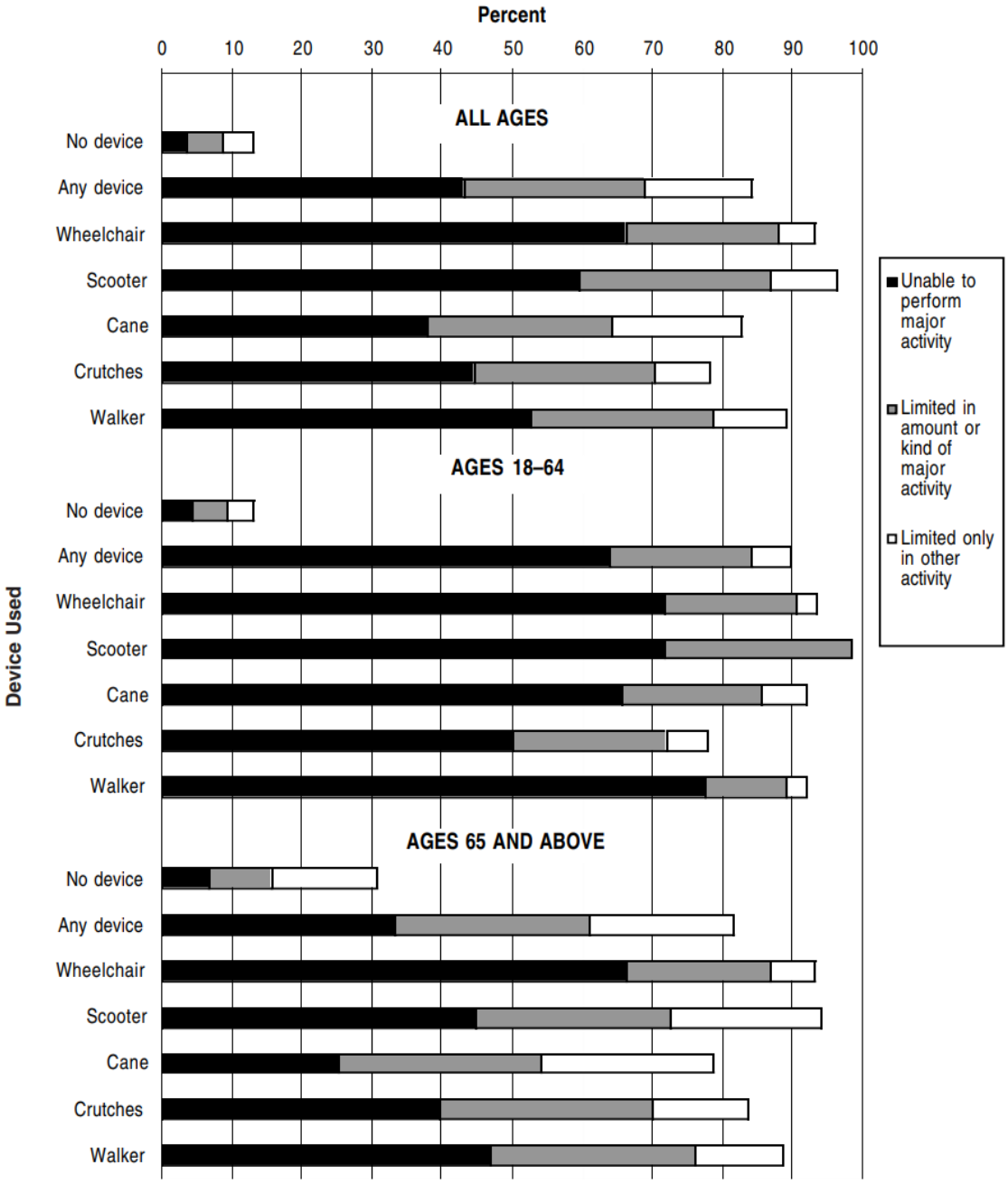


Figure 8 Proportion of mobility device users and non-users limited in activity, by age and device

(2000, p. 17)

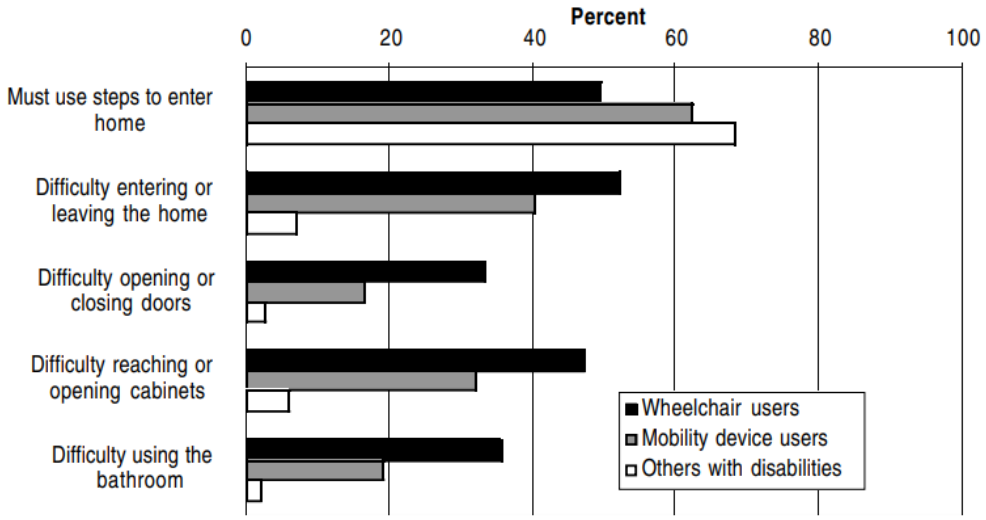


Figure 9 Proportion of mobility device users and non-users with home accessibility difficulties, by type of difficulty and device, ages 18 and above (Kaye et al., 2000, p. 32)

2.4.3 Dimensions of Common Mobility Aids

Mobility aids come in a variety of sizes and require different operating spaces, and those dimension and data have a huge impact in the design of living spaces. For example, wheelchairs need enough space to pass and turn, especially in areas such as doorways, bathroom, and kitchen. This section lists dimensions of a few common mobility aids.

For ambulant mobility aids, such as the crutch, cane and walker, the footprint is smaller compared to the wheelchair, but sufficient space is required to ensure safe and comfortable operation (See figure 10).

Wheelchair dimensions vary by type and manufacturer, so for more accurate results the wheelchair used by the user should be measured individually. The length of the wheelchair is important to know because it determines the turning radius (Panero & Zelnik, 1979). Figures 11~15 list some common dimensions for wheelchairs (Goldsmith, 2000).

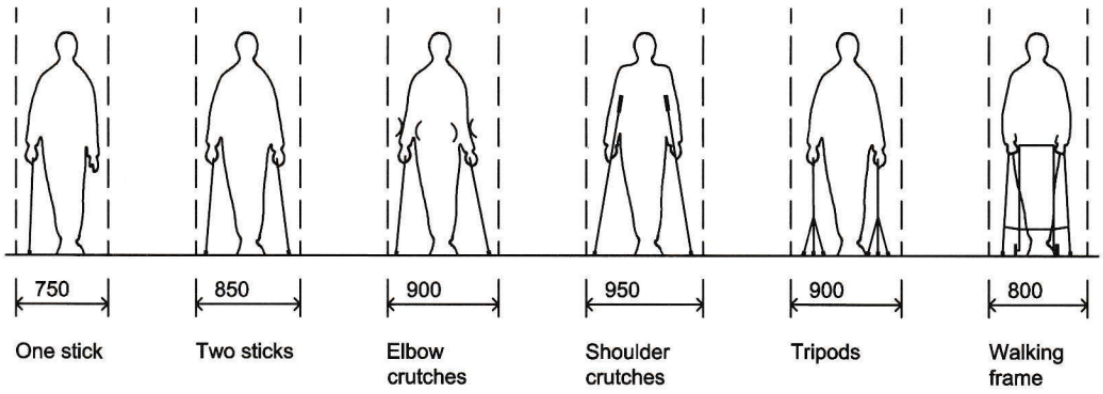


Figure 10 Ambulant disabled people, utilization space for forward movement (p. 19)

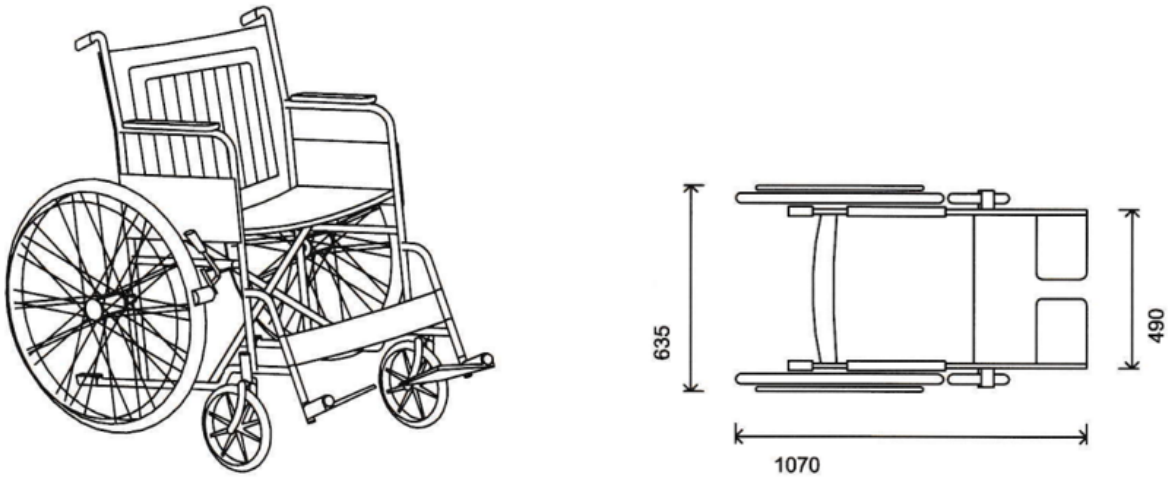


Figure 11 Standard wheelchair the height above floor level of the top face of the handles is 920 mm and of the top face of the armrests 750 mm (p. 19).

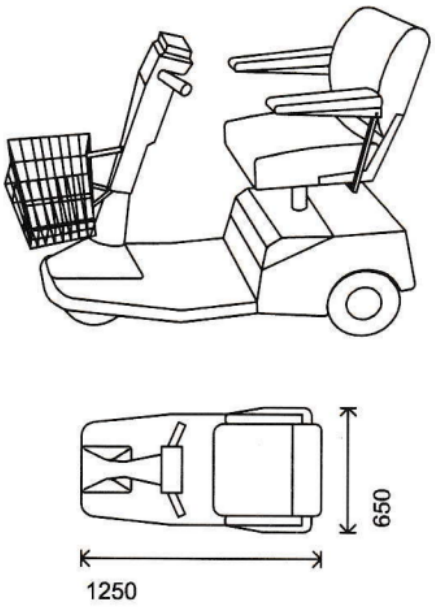
Figure 12 (Lift) Attendant-pushed wheelchair and width 635 mm, length 790 mm (p. 20)

Figure 13 (Right) Wheelchair with elevated leg rests reclining back, width 635 mm length 1300 mm (p. 20)

Figure 14 (Lift) Powered wheelchair width 670 mm length 1110 mm (p. 20)

Figure 15 (Right) Powered wheelchair width 630 mm, length 990 mm (p. 20)

Electric scooters are larger and require more room to operate. They are also usually for outdoor use. Figure 16 lists the average size of a three-wheel scooter and a four-wheel scooter.



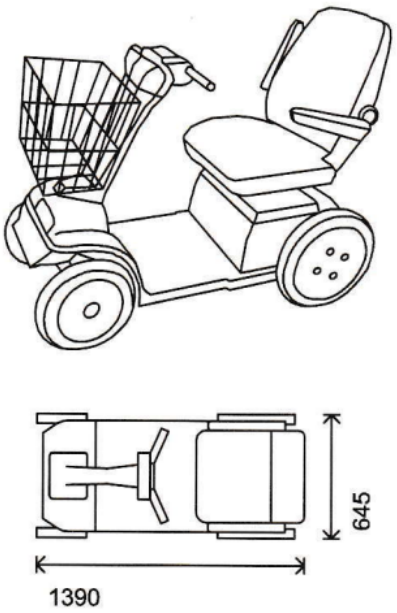


Figure 16 (Lift) Three-wheel scooter (p. 21)

Figure 17 (Right) Four-wheel scooter (p. 21)

Considering these dimensions is very important when designing independent living environment for people with mobility issues. An appropriate space size can effectively improve operability, accessibility and safety. Designers should refer to the standards and dimensions from the ADA, but the specific situation needs vary according to every individual user. The general size and operational requirements of mobility aids provide designers a foundation and convenient starting point, but they need to recognize the uniqueness of each user. It is necessary to learn mobility aid that the user has used, not only for the physical size of the device, but also to know the usage method to achieve a better design.

In addition, understanding anthropometry is essential for ergonomic, rationality and comfort of designing. This research strives to put the unique characteristics and needs of the users first.

2.5 Anthropometry

The earliest written interest and study of human body size can be traced back to Rome in the 1st century BC, when Vitruvius wrote about the proportions of human body in a treatise about architecture from antiquity that mentioned:

> in the human body the central point is naturally the navel. For if a man be placed flat on his back, with his hands and feet extended, and a pair of compasses centred at his navel, the fingers and toes of his two hands and feet will touch the circumference of a circle described therefrom. And just as the human body yields a circular outline, so too a square figure may be found from it. For if we measure the distance from the soles of the feet to the top of the head, and then apply that measure to the outstretched arms, the breadth will be found to be the same as the height as in the case of plane surfaces which are perfectly square.(Morgan, 1960, p. 73)

Then, Leonardo da Vinci was inspired by Vitruvius to create the famous painting “Vitruvian Man” (Figure 18) during the Renaissance. Beside this, there are many ideas and opinions about the size and proportion of the human body. During the Middle Ages, a monk of Phourna of Agrapha named Dionysius came up with "nine heads tall" as the men’s body scale and in the 15th century, the Italian Cennino Cennini descried that the height of a man is equal to the width of the arms extended (Pierre & Jacques, 1965). It can be found that during the Middle age, the study of the human body stayed focused on the overall proportion and had not begun to focus more accurate measurement on various parts of the human body.

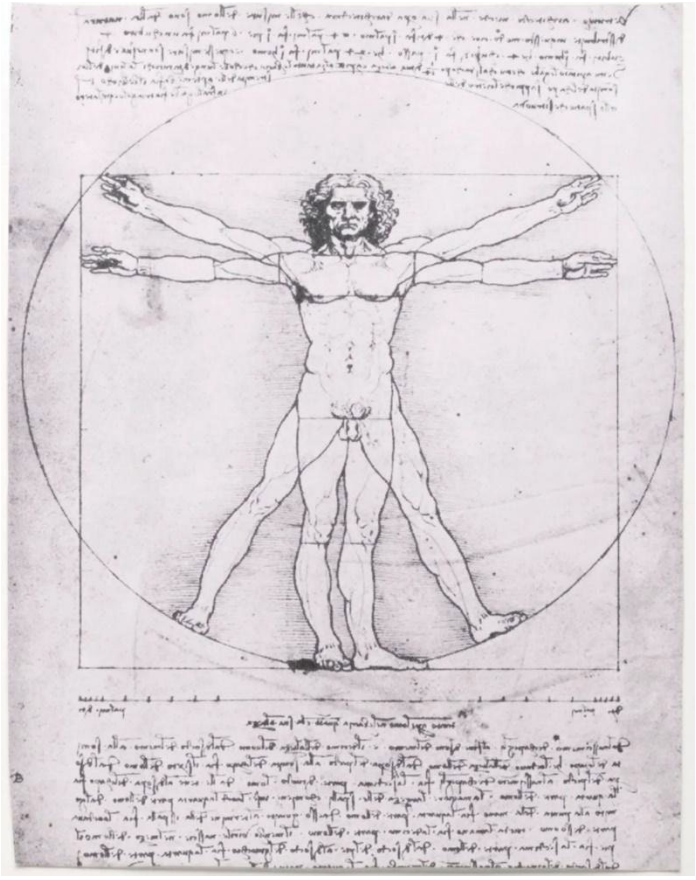


Figure 18 Vitruvian Man, drawing by Leonardo da Vinci, c. 1490

By the time of World War Two, as military equipment needed to be highly matched and coordinated with the people who used them, people began to realize the importance of human factors in design, especially in terms of human body size (Panero & Zelnik, 1979). Henry Dreyfuss was commissioned by the U.S. Department of Defense to develop ergonomic standards for the design of military equipment. He conducted many sample surveys and measurements of adult men serving in the military and the results and data of this survey provides a lot of data for The Measure of Man, which was later published (Hamraie, 2017).

The above is the history of exploration of the human body in different periods. It can be seen that the consideration of human body size/dimension has been an indispensable part of

design from ancient times to the present, and the study topic of this article is based on user body data as the design basis. Therefore, studying and applying anthropometry is essential.

2.5.1 "Human Template"

A definition from Cambridge Advanced Dictionary defined "template" as "a method or system that can be copied and used by others" (Cambridge Dictionary, 2023), so the "Human Template" can mean: a human method or system that can be copied and used by other human. For the purposes of this thesis, the project does not agree with only using the "human template" data as the references for all design.

For centuries, a universal body has been defined by a specific image of a European, white, non-disabled, strong male (Hamraie, 2017). This is not Anthropometry; this is just the dream of a "perfect body". The emergence of this single image is discriminatory and segregates people who deviate from the "standard", such as women, people with different color, and disabilities (Ben-Moshe et al., 2014). Later, there were some architects and designers actually measured and recorded the numerical values of the human body, but most of the images shown in books were all able-bodied men or able-bodied people with no obvious gender identity. As late as 1981, the *Architectural Graphic Standards (7th Edition)* included anthropometric images of a man and a woman, and on adjacent pages showed a wheelchair user and a cane user (Figure 19) along with some design suggestions (Hamraie, 2017). This is a very important step forward, recognizing the diversity of the human body and pluralism in future design.

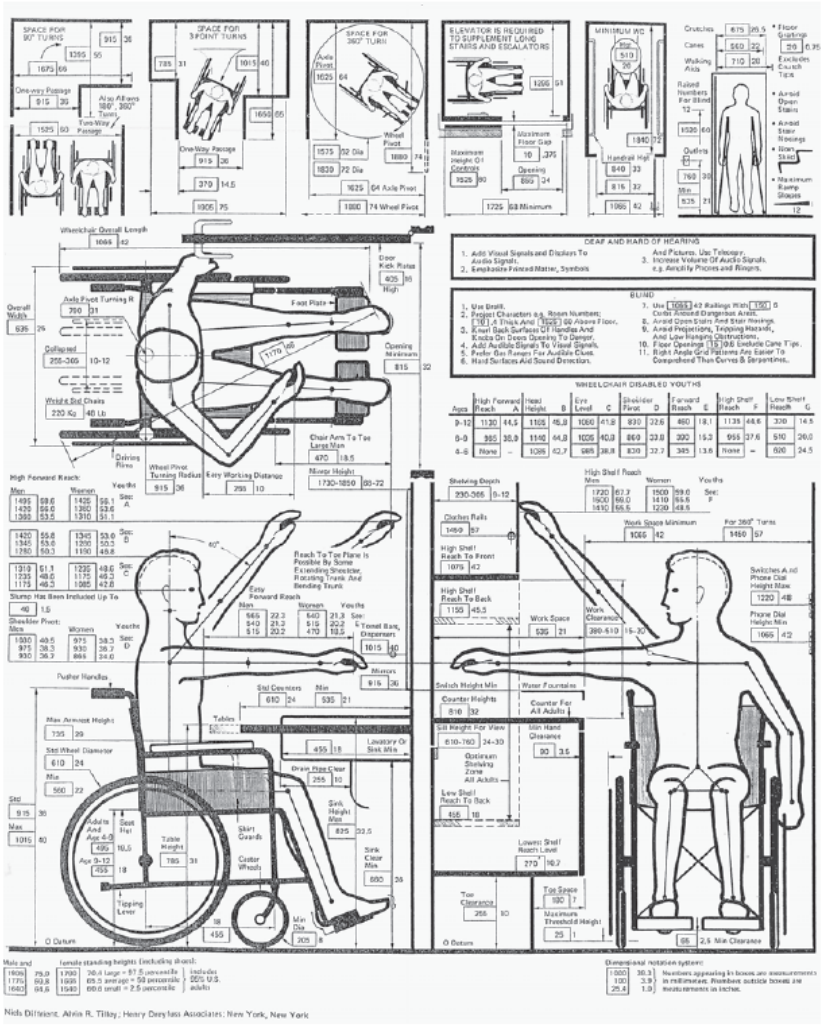


Figure 19 Anthropometric figures of wheelchair user and canes user by Charles Ramsey and Harold Sleeper (Hamraie, 2017, p. 32)

After that, the famous industrial designer Henry Dreyfuss integrated scientific results and data from different fields into a book *The Measure of Man* published in 1967. The data presented in this book showed his research of ergonomics and human factors across a variety of industries and fields; in the era of mass production, those data and research could provide useful human body generalizations for different fields (Hamraie, 2017). Compared with advocating "standardization", this book emphasizes the diversity and dynamics of users. As Henry Dreyfuss

Associates' motto states: "We bear in mind that the object being worked on is going to be ridden in, sat upon, looked at, talked into, activated, operated, or in some other way used by people" (Panero & Zelnik, 1979).

However, after reading the above-mentioned books and research, it can be found that the data measurements and analysis of disabled people are very limited. The data presented are very simple compared with those able-bodied research. For example, there is less data collection based on different genders and ages of people with disabilities. Because of individual differences, general data will affect design results. Therefore, the study believes that studying the methods of anthropometry is more important than knowing the standard number. As mentioned above, anthropometry is a specialized discipline that measures, studies and analysis human body characteristics which cannot simply be regarded as only measurement data. It is very complex and difficult to understand the characteristics of a group through measurement data. For example, human body shapes and heights are not static and different ages, genders, and races will affect the survey results (Panero & Zelnik, 1979), so this subject is very difficult to master. In this study, it is more important to know how to apply those data to space planning and furniture design. Therefore, the following section will talk about specific anthropometric methods and applications in design.

2.5.2 Data Collection in Designing Living Space

When designing interior spaces, it is usually impacted by two types of human body data: static dimensions and dynamic dimensions. Static dimensions, also called structural dimensions, include measurements of the head, torso, and limbs in standard positions. Dynamic dimensions, also called functional dimensions, include data measurements during movement when doing some actions and working (Panero & Zelnik, 1979, p. 39). Of course, human body data is not

limited to these two types. There are nearly 1,000 measurement types in the medical field, but those data are less useful for this study.

The book, The Human Body in Equipment Design (DAMON, 2014) wrote:

> "If one wishes to describe a group for human engineering purposes, the ten most important dimensions to obtain are in order: height; weight; sitting height; buttock-knee and buttock-popliteal lengths; breadths across elbows and hips, seated; knee and popliteal heights; and thigh clearance height." (2014, p. 2)

The measurement of these ten dimensions is also an essential part of the subsequent design of this study. Figure 20 shows those body measurements are the most significant to the interior designer and industrial designer.

In addition, the range of motion of the joint is also an important date that designers need to pay attention to. The degree that the joints can move or rotate greatly affects the interaction between the people and the environment. Nevertheless, accurately measuring the dimensions of human joints during movement is very complex and requires professional equipment and technicians. Therefore, designers who do not have these abilities and equipment should measure the range of joint movement: the angle formed between the two extreme positions, which can effectively aid in designing spaces and furniture for specific users (Panero & Zelnik, 1979) as shown in Figure 21 .

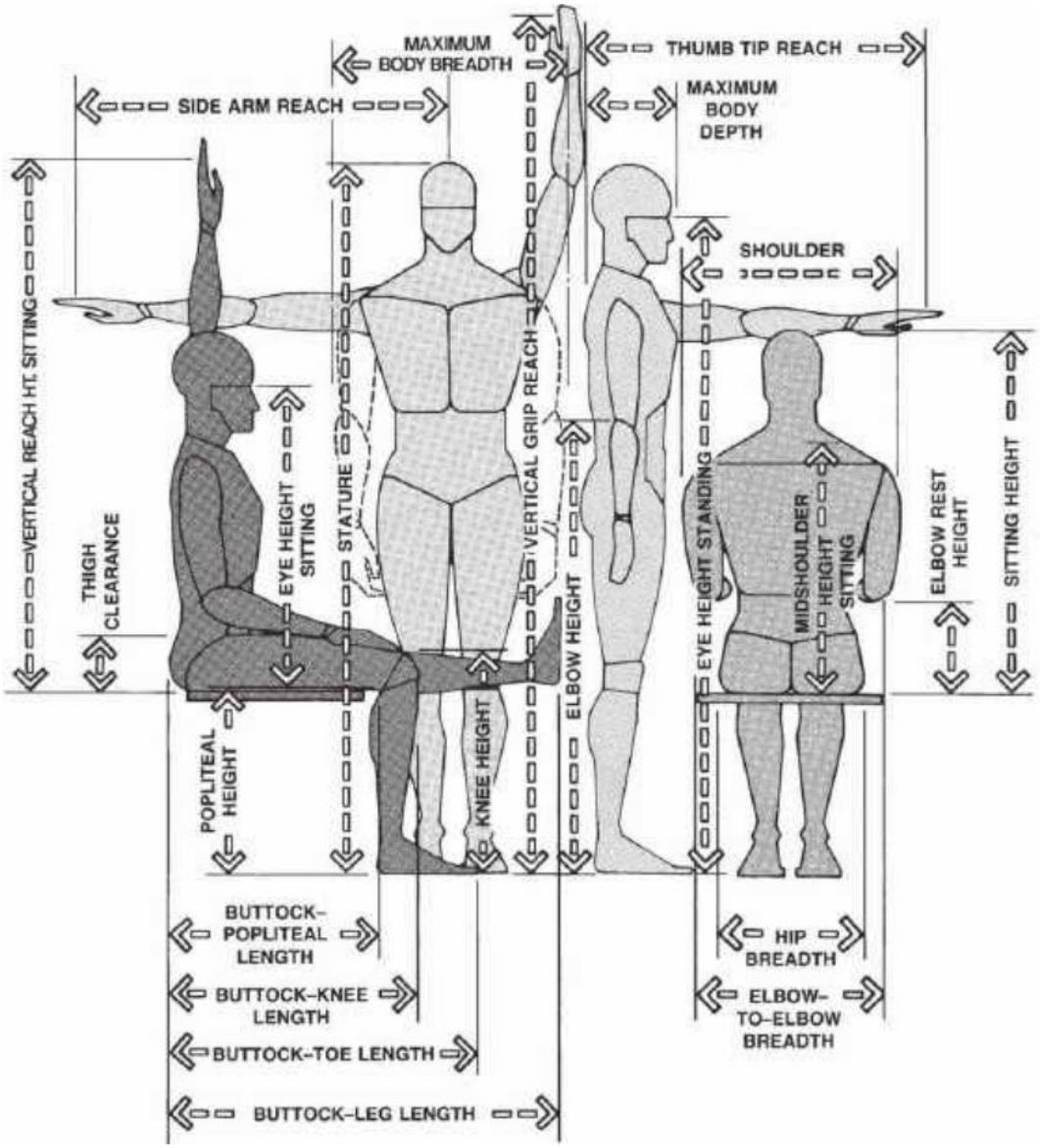


Figure 20 body measurements of most use to the interior designer (Panero & Zelnik, 1979, p. 43)

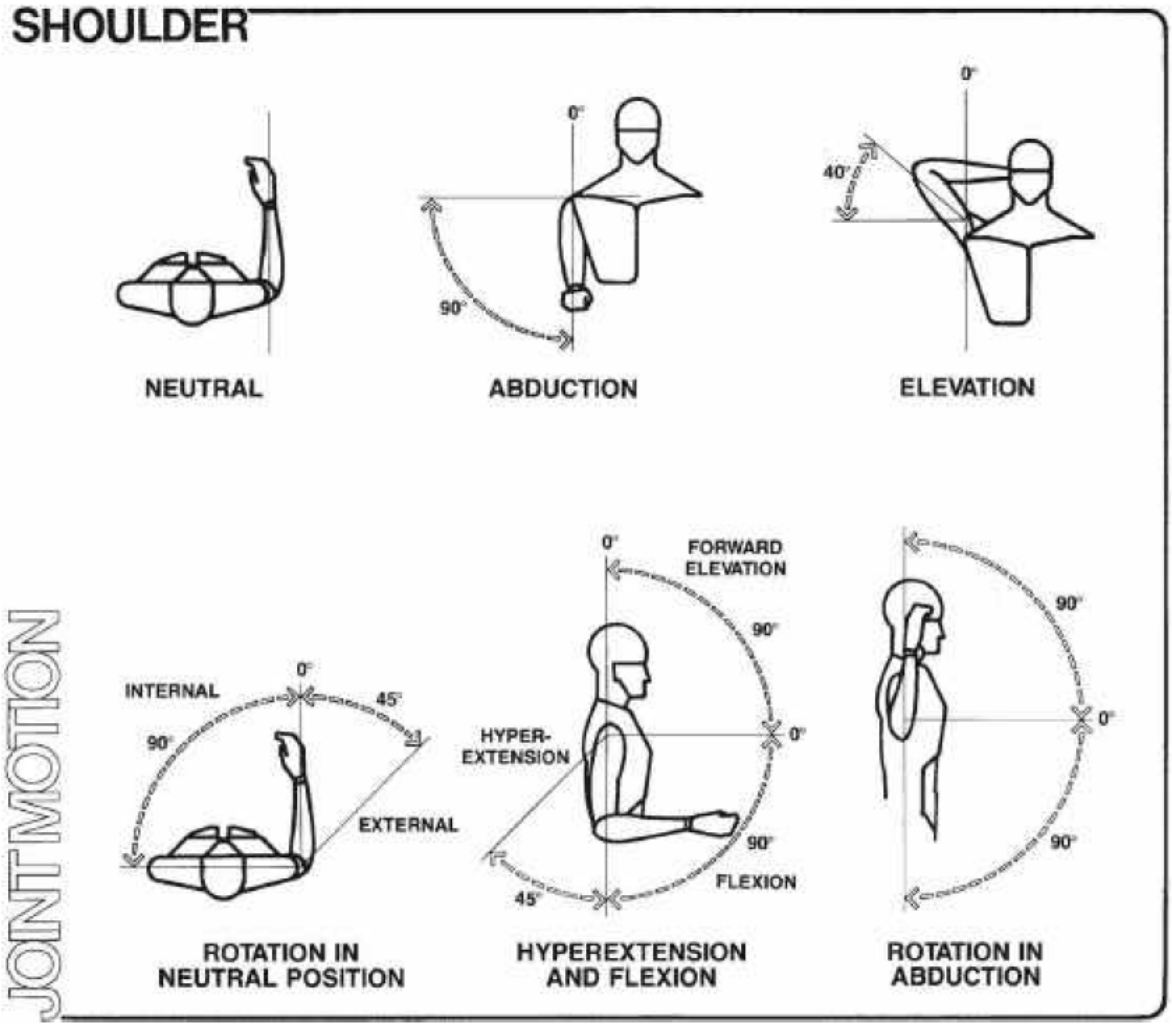


Figure 21 joint motion of shoulder (Panero & Zelnik, 1979, p. 223)

According to the specific needs and requirements of the user, additional size measurements are required in specific cases. For example, wheelchair users need to sit in the wheelchair to complete most of their daily tasks, so their human body size needs to be considered and measured together with mobility aid. Thus, this study will discuss more about the application of anthropometric to people with mobility issues in the next section.

2.5.3 Anthropometric in Mobility Issues

As mentioned above, most anthropometric data are related to the military, so the representation of the data will be limited by age, gender, and physical condition. However, elderly people and disabled people are the two main research groups in this study. Due to the particularity and diversity of target groups, the data results involve many variables, which increases the difficulty of measurement. Therefore, the relevant anthropometric data are relatively simple and lacking both in terms of measurement base and result (Panero & Zelnik, 1979). Of course, due to the trend of an aging population and the large number of people with disabilities, there is also related literature that has been focused on both groups. However, a common problem is that the information regarding these two groups was small and limited (1979, p. 84). Therefore, it is not enough to just use existing group data to design for individuals; learning from group data can help designers consider possible body change trends in their target groups.

From the data on young people and elderly people, it can be found that after 18 to 24 years old, the height decreases along with an age increase (see Figure 22). There are two reasons for this result. One is that the older people sample are from an earlier generation (older generations are generally shorter than people born later). The other reason is the aging process; as the age increases, the body gets old, the height also tends to decrease. The recent data shows that people's height is generally on the rise (Panero & Zelnik, 1979). The book *Human Dimension & Interior Space* summarized the National Health Survey data of American citizens aged 18 to 79 at that time and got the conclusion: "Reach measurements of old people are shorter than young people" (1979, p. 84). As the elderly age, arthritis and aging joint will limit movement (1979, p. 85).

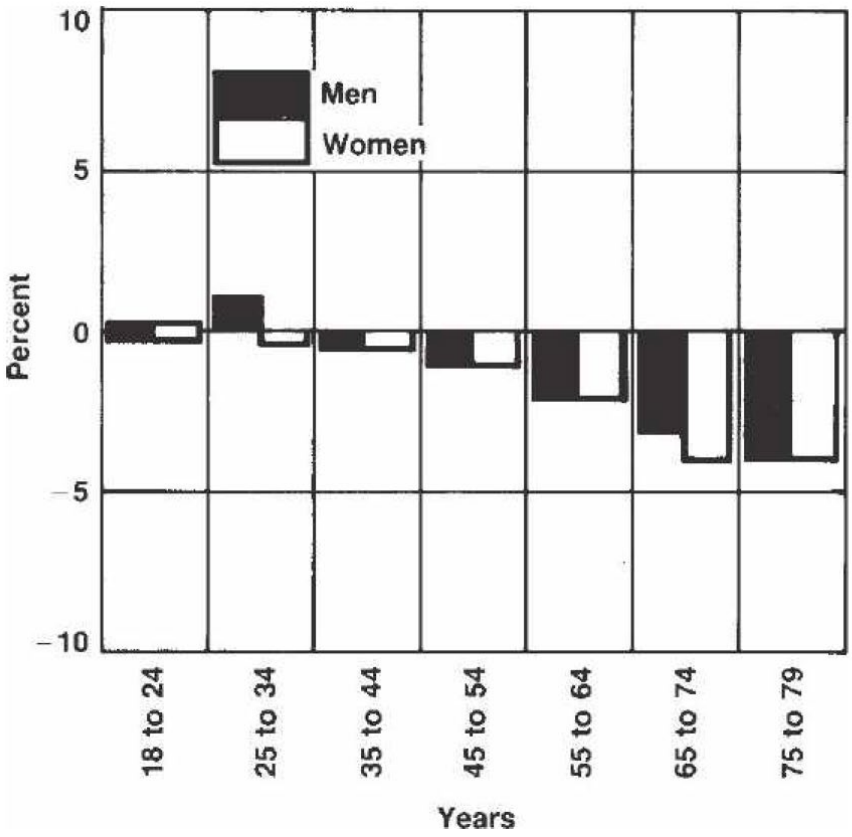


Figure 22 Relative change in height with age over the mean for men and women (Panero & Zelnik, 1979, p. 34)

For the group of people with disability resulting in limited movement, it is difficult to use a few data points to represent the characteristics of this group due to individual differences and the diversity of mobility devices, so communicating with users to understand their needs and habits are very necessary. As shown in Figure 23 and Figure 24, when doing the body data collection for wheelchair users, measurements need to be made with their wheelchair. The size and height of the wheelchair will significantly affect the measurement results, leading to different requirements. Figure 25 shows the key measurements for crutch users that designers need to pay attention to. It can be seen from Figure 25 that the gap between the user and the crutch (D & E) will affect the amount of space (B&C) that is enough for moving. For mobility

device users, the tools, devices, or equipment are regarded as part of their bodies that help them better accomplish everyday work, so designers cannot consider the device and user separately.

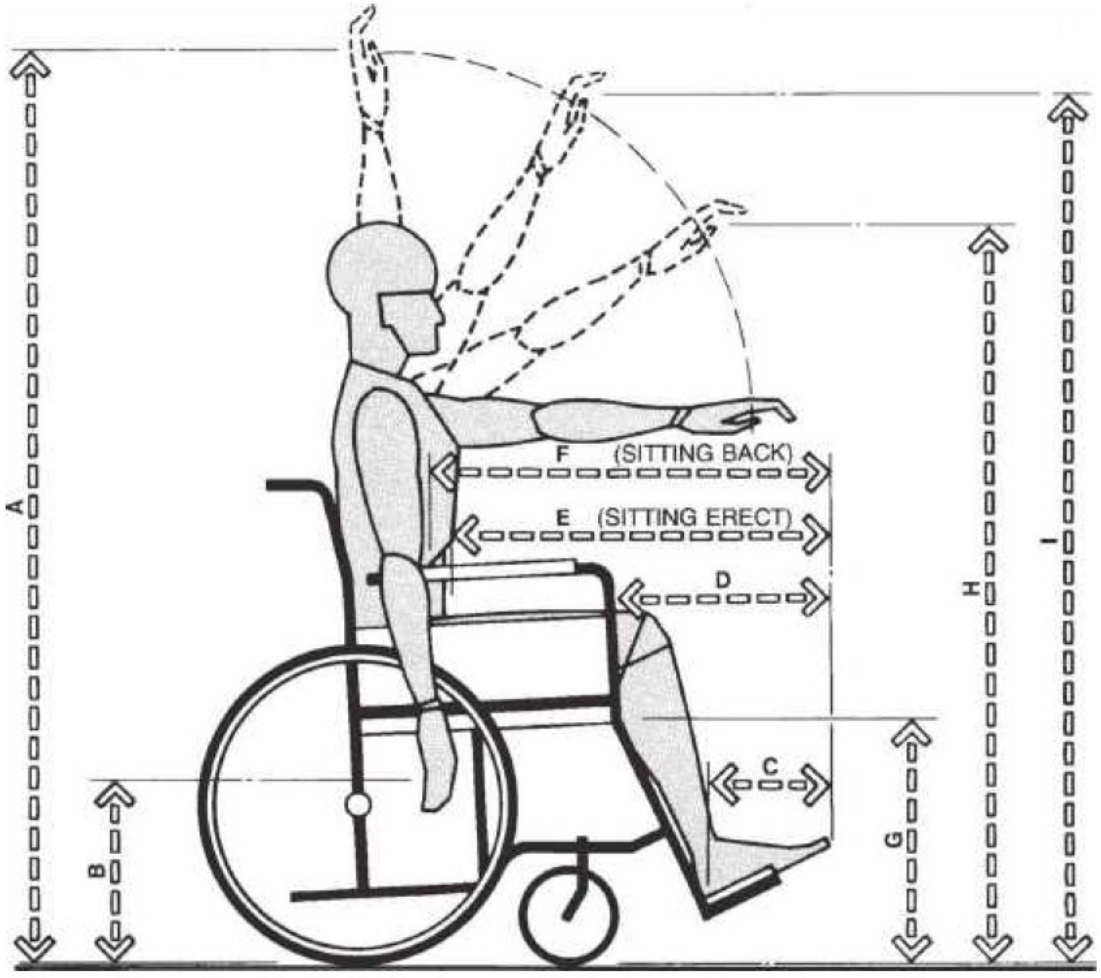


Figure 23 Anthropometrics of chairbound people – side view (Panero & Zelnik, 1979, p. 92)

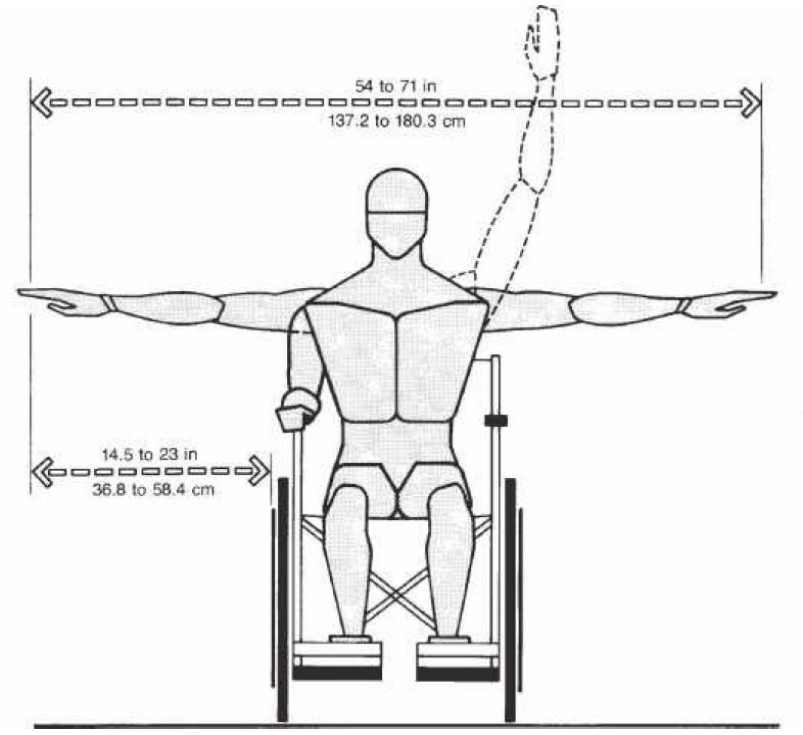


Figure 24 Anthropometrics of chairbound people – front view (1979, p. 94)

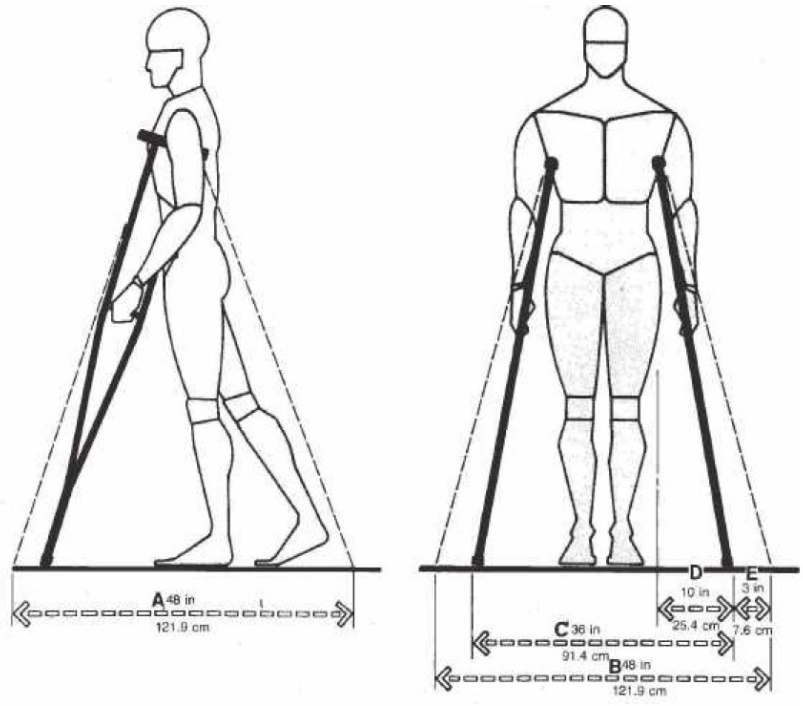


Figure 25 Anthropometrics of people use crutches (1979, p. 95)

2.5.4 Limitation and Considerations

Learning existing anthropometrics data can indeed help designers understand and know basic human body dimensions to design inclusive products, but as this chapter has been emphasizing, only relying on "big data" cannot satisfy everyone’s unique/diverse requirements. When facing a large amount of data, designers should not rely too much on existing “numbers” or ignore the uniqueness of the users themselves.

The author believes that if possible, measuring individual body measurements of users is the best way. However, as mentioned above, anthropometry is really complex and requires specialized knowledge and skills. If measure without the proper expertise, getting incorrect measurements is useless. Therefore, for designers who do not have specialized knowledge in anthropometry, understanding the purpose of each measurement and combining existing anthropometric data with user needs is the most effective way.

2.6 Daily life Assessment Form

After learning about mobility devices and anthropometrics, designers also need to know users' physical performance and specific problems encountered in daily life. This chapter will introduce three assessment tools that are used to evaluate Activities of Daily Living (ADL) or Instrumental Activities of Daily Living (IADL), analyze their characteristics, and develop an evaluation tool for the design guideline of this study.

2.6.1 ADL and IADL

The Activities of Daily Living (ADL) and Instrumental Activities of Daily Living (IADL) are the term often used in healthcare, first coined by Sidney Katz in 1950 (Katz, 1983).

ADL refers to the everyday basic activities and skills that are fundamental to living independently (Association, 2014). The basic ADLs include six categories: dressing, ambulating, bathing, eating, transferring, and toileting (Edemekong et al., 2023).

IADL refers to more complex daily activities and skills within the home and community, such as managing finances, shopping, and house working, such as washing dishes and doing laundry (Pashmdarfard & Azad, 2020).

Health and rehabilitation systems often use ADL and IADL to help identify the people who require help and services. According to this study's service group and design direction, evaluating the user's daily living activities effectively helps designers better identify user demand, discover, and solve problems. The next section will introduce three assessment tools for ADL and IADL.

2.6.2 Katz Index of Independence in Activities of daily Living

The Katz Index of Independence in Activities of Daily Living, also called Katz ADL is the most appropriate tool to measure a person's ability to live independently on a daily basis (McCabe, 2019). The target population of Katz ADL is older people and they fill in the form by themselves (self-report). There are 6 ADL function items in this tool (Figure 26), listed as bathing, dressing, toileting, transferring, continence, and feeding. The Maximum score is 6, from fully independent to a minimum score of 1, or very dependent. A score of 6 indicates full function, 4 is moderate impairment, and 2 or less means severe functional impairment (Pashmdarfard & Azad, 2020).

Katz Index of Independence in Activities of Daily Living

ACTIVITIES POINTS (1 OR 0)	INDEPENDENCE: (1 POINT) **NO** supervision, direction or personal assistance	DEPENDENCE: (0 POINTS) **WITH** supervision, direction, personal assistance or total care
BATHING POINTS:_____	(1 POINT) Bathes self completely or needs help in bathing only a single part of the body such as the back, genital area or disabled extremity.	(0 POINTS) Needs help with bathing more than one part of the body, getting in or out of the tub or shower. Requires total bathing.
DRESSING POINTS:_____	(1 POINT) Gets clothes from closets and drawers and puts on clothes and outer garments complete with fasteners. May have help tying shoes.	(0 POINTS) Needs help with dressing self or needs to be completely dressed.
TOILETING POINTS:_____	(1 POINT) Goes to toilet, gets on and off, arranges clothes, cleans genital area without help.	(0 POINTS) Needs help transferring to the toilet, cleaning self or uses bedpan or commode.
TRANSFERRING POINTS:_____	(1 POINT) Moves in and out of bed or chair unassisted. Mechanical transferring aides are acceptable.	(0 POINTS) Needs help in moving from bed to chair or requires a complete transfer.
CONTINENCE POINTS:_____	(1 POINT) Exercises complete self control over urination and defecation.	(0 POINTS) Is partially or totally incontinent of bowel or bladder.
FEEDING POINTS:_____	(1 POINT) Gets food from plate into mouth without help. Preparation of food may be done by another person.	(0 POINTS) Needs partial or total help with feeding or requires parenteral feeding.

TOTAL POINTS = _____ *6 = High (patient independent) 0 = Low (patient very dependent)*

Figure 26 Katz Index of Independence in Activities of daily Living (McCabe, 2019)

2.6.3 Barthel Index

The Barthel Index was developed in 1955 by Mahoney and Barthel (1965). This tool (Figure 27) lists 10 activities related to ADL: feeding, bathing, grooming, dressing, bowels, bladder, toilet use, transfers, mobility, and stairs. Compared with the Katz ADL, the Barthel index includes more mobility-related items - mobility and stairs, and divides continence into more detailed items - Bowels and Bladder. The Barthel Index also uses self-report to collect information (Pashmdarfard & Azad, 2020). Each domain is scored from 0, indicating maximum disability and dependency, to 10 or 15, the maximum strength and independence (2020); the higher score indicates more independence. The Barthel Index is often used to evaluate stroke patients and to observe functional abilities change after rehabilitation (Taghizadeh et al., 2020).

2.6.4 Lawton Instrumental Activities of Daily Living Scale

The Lawton Instrumental Activities of Daily Living Scale (Lawton IADL Scale) was developed by Lawton and Brody in 1969 to assess user's independent daily living skills (Pashmdarfard & Azad, 2020). This tool lists 8 domains (Figure 28): ability to use the telephone, shopping, food preparation, housekeeping, laundry, mode of transportation, responsibility for own medications, and ability to handle finances. The Lawton IADL Scale is considered a more complex version of the Katz Index. The tool is useful to identify a person's functional ability at present and also can assess improvement or deterioration over time (McMahon, 2007). Each domain is scored 0 and 1, and total scores are between 0 to 8, which is from low functional (dependence) to high functional (independence). In addition, this scale noted women can answer all 8 questions, but men can choose not to answer housekeeping, food preparation, and laundry (Pashmdarfard & Azad, 2020).

Barthel Index Activity	Score
FEEDING 0 = unable 5 = needs help cutting, spreading butter, etc. or requires modified diet 10 = independent	
BATHING 0 = dependent 5 = independent (or in shower)	
GROOMING 0 = needs help with personal care 5 = independent face/hair/teeth/shaving (implements provided)	
DRESSING 0 = dependent 5 = needs help, but can to about half unaided 10 = independent (including, buttons, zips, laces, etc.	
BOWELS 0 = incontinent (or needs to be given enemas) 5 = occasional accident 10 = continent	
BLADDER 0 = incontinent, or catheterized and unable to manage alone 5 = occasional accident 10 = continent	
TOILET USE 0 = dependent 5 = needs some help, but can do something alone 10 = independent (on and off, dressing, wiping)	
TRANSFERS (BED TO CHAIR AND BACK) 0 = unable, no sitting balance 5 = major help (one or two people, physical), can sit 10 = minor help (verbal or physical) 15 = independent	
MOBILITY (ON LEVEL SURFACES) 0 = immobile or < 50 yards 5 = wheelchair independent, including corners, > 50 yards 10 = walks with help of one person (verbal or physical) > 50 yards 15 = independent (but may use any aid; for example, stick) > 50 yards	
STAIRS 0 = unable 5 = needs help (verbal, physical, carrying aid) 10 = independent	

Barthel Index (adapted from Mahoney & Barthel, 1965)

Figure 27 Barthel Index (Kevdzija, 2020)

Patient Name:_____ **Date:**_____

Patient ID #_____

LAWTON - BRODY
INSTRUMENTAL ACTIVITIES OF DAILY LIVING SCALE (I.A.D.L.)

Scoring: For each category, circle the item description that most closely resembles the client's highest functional level (either 0 or 1).

A. Ability to Use Telephone		**E. Laundry**	
1. Operates telephone on own initiative-looks up and dials numbers, etc.	1	1. Does personal laundry completely	1
		2. Launders small items-rinses stockings, etc.	1
2. Dials a few well-known numbers	1	3. All laundry must be done by others	0
3. Answers telephone but does not dial	1		
4. Does not use telephone at all	0		
B. Shopping		**F. Mode of Transportation**	
1. Takes care of all shopping needs independently	1	1. Travels independently on public transportation or drives own car	1
2. Shops independently for small purchases	0	2. Arranges own travel via taxi, but does not otherwise use public transportation	1
3. Needs to be accompanied on any shopping trip	0	3. Travels on public transportation when accompanied by another	1
4. Completely unable to shop	0	4. Travel limited to taxi or automobile with assistance of another	0
		5. Does not travel at all	0
C. Food Preparation		**G. Responsibility for Own Medications**	
1. Plans, prepares and serves adequate meals independently	1	1. Is responsible for taking medication in correct dosages at correct time	1
2. Prepares adequate meals if supplied with ingredients	0	2. Takes responsibility if medication is prepared in advance in separate dosage	0
3. Heats, serves and prepares meals, or prepares meals, or prepares meals but does not maintain adequate diet	0	3. Is not capable of dispensing own medication	0
4. Needs to have meals prepared and served	0		
D. Housekeeping		**H. Ability to Handle Finances**	
1. Maintains house alone or with occasional assistance (e.g. "heavy work domestic help")	1	1. Manages financial matters independently (budgets, writes checks, pays rent, bills, goes to bank), collects and keeps track of income	1
2. Performs light daily tasks such as dish washing, bed making	1	2. Manages day-to-day purchases, but needs help with banking, major purchases, etc.	1
3. Performs light daily tasks but cannot maintain acceptable level of cleanliness	1	3. Incapable of handling money	0
4. Needs help with all home maintenance tasks	1		
5. Does not participate in any housekeeping tasks	0		
Score		**Score**	

Total score_____

A summary score ranges from 0 (low function, dependent) to 8 (high function, independent) for women and 0 through 5 for men to avoid potential gender bias.

Figure 28 Lawton Instrumental Activities of Daily Living Scale (McMahon, 2007)

2.6.5 Discussion and Conclusion

This section introduced three assessment tools, two for evaluating ADL (Katz Index and Barthel Index) and one for evaluating IADL (Lawton IADL). All three tools use the self-report model to assess the user's functional activities and independence during daily living, usually for elderly people and stroke patients. They are all free and do not require any special training or course and no additional equipment is required (Pashmdarfard & Azad, 2020) which is appropriate for use by non-medical professionals and self-tests. The questions in these tools are simple and take a short time to complete, usually between 5 to 10 minutes, which is very friendly to the elderly and patients with poor energy. Questions that are too long or too complex may cause difficulty or exhaustion for users (Dutil et al., 1990).

ADL assessment tools divide daily activities into several basic domains to determine the user's independent ability in different daily skills, thereby developing unique treatment or rehabilitation plans for patients. Referring to this point, the tool developed in this study can divide the living space into several categories according to area/function, and based on the user's answers, specific daily challenges and problems can be discovered for the designers to carry out more targeted design or modification. In the Lawton IADL Scale, there are two different scoring standards for men and women, men can choose not to answer questions related to cooking and laundry, because this is often considered as women's work, resulting in men's lack of response to those questions and leading to inaccurate rating (not because of inability to do those activities) (Pashmdarfard & Azad, 2020). The author believes it is advisable to adjust questions and standards based on user differences, but not by gender. Men can ask for a larger kitchen only because they like to cook, and women can also ask for a more suitable living setup based only on their own preferences.

The above three tools all use a scoring method to determine the user's independent ability by counting the final score, but this is not applicable to this study. The purpose of this article is not to know the user's independence level, but to perceive the users' difficulties and obstacles in daily independent life, and then design a more convenient “self-supporting” living space. This article tries to develop a specific tool/form for this study that is performance-based and user-centered.

2.7 Furniture for People with Mobility Issues

Furniture is an indispensable part of people's daily life activities. Inappropriate furniture will not only cause trouble in users' daily lives but may cause injuries when people use it. Therefore, it is essential to choose or design furniture that is appropriate to the user and promotes their independence in daily life.

This section will start from the premise of understanding user needs, focusing on safety, ergonomics, and durability, to provide suggestions for designers in choosing/designing furniture. This section will also point out the main considerations and potential problems based on living space functionality (kitchen, bedroom, bathroom, others).

2.7.1 Know the Users

One of the main reasons furniture can not meet users’ needs is due to poor communication between design/manufacturers and users, as well as failure to understand the diverse needs of the mobility issue group (Jonsson, 2013). Therefore, communicating and understanding with users is the foundation of designing suitable furniture.

Aging is a typical process of decline in various body functions; strength and muscle mass loss will lead to old people becoming slower in movement and reducing body flexibility (Keller

& Engelhardt, 2014). Compared with younger people, the operational accessibility of the elderly is limited, so inappropriate furniture (too high, too low) can cause them to do actions which are beyond their physical performance, such as frequent bending, squatting, or standing on tiptoes. Such actions may result in falls, injuries or even aggravating their diseases (Shi & Zhang, 2023). Those all can be potential risks in daily activities. Additionally, the hearing, vision, and reaction abilities of seniors will decrease with age (Hrovatin et al., 2012), so when designing or choosing furniture, especially smart furniture, that problem should be taken into consideration.

For people who have limited mobility and require assistive devices, it is even harder to find adequate furniture due to physical conditions and diverse tools. Unsuitable furniture will not only hinder independence in daily activities but also erode morale and cause some psychological issues, such as a sense of inferiority, depression, or other problems (Imrie & Hall, 2001).

The size of furniture appropriate for the wheelchair user largely depends on the dimensions of the wheelchair and the user's reach range while sitting on it. In addition, wheelchair users may face challenges during the "Transfer" process (moving back and forth from the wheelchair to the target object). Furniture with improper heights can exacerbate the difficulty of the movement process and even lead to injuries. The other users who use manually powered devices, such as walkers, canes, and crutches, generally move slowly, and when the action involves larger movements (such as reaching an object at a high place), body balance can be affected (Li et al., 2011).

In conclusion, choosing/designing furniture needs to consider the safety of the user so as to avoid injuries during use. Due to the particularity of the user, it is necessary to ensure the usability of furniture based on their human body data. Considering the long-term use of the furniture, durable and easy-to-clean furniture can greatly improve life quality.

2.7.2 Three Main Categories of Furniture Usability

According to related articles and research, trying to classify user needs results in three main categories: safety, ergonomics, and durability.

Safety is the highest priority and the most important category to be considered. Whether the impact of aging or disability, both can lead to slower movement and reduced body flexibility. Therefore, behaviors such as standing, sitting, bending, and so on in daily life will cause some obstacles, especially for some mobility device users, since much furniture is designed without considering the device size, making it hard for disabled individuals to avoid hidden safety hazards in daily life, such as furniture tipping over, bumps and falls (Chi & Shi, 2024). The selection of carpets and rugs needs to be careful because the movement and curling of carpets may cause people to trip or hinder the movement of the wheelchair (Lawlor & Thomas, 2008, p. 63). Furniture should be stable and not be tipped over and should provide gripping support to reduce the risk of falling, in addition, furniture should avoid all sharp edges and corners, which can pose great risks (Kamperidou, 2017). Research shows that designing and modifying living spaces according to the needs of the elderly could reduce the risk of injury by 30% to 50% (Hrovatin et al., 2012).

Ergonomics is the foundation of furniture design. A common problem is that the user's body dimensions do not match their furniture. Elderly people often face the problem of chairs and tables being too high and drawers being too low, which can lead to a negative impact on their health (Kamperidou, 2017). Wheelchair users often encounter issues such as closet rods being too high, upper storage cabinets being unusable, lower ones being inconvenient, or other kinds of furniture and designs that are beyond their arm's reach (Chi & Shi, 2024). In order to choose/design appropriate furniture, the collection and application of user body data is basic.

Adjustable furniture and adaptive furniture may also be a solution. Ergonomics is not only about dimensions. An ergonomic bed design can ensure the spinal column is kept in the right position while sleeping to achieve maximum relaxation (Smardzewski et al., 2005). The application of ergonomics can effectively reduce the risk of injury, discomfort, and disease (Pinto et al., 1997).

Durability makes the longer lifespan of the furniture. Jonsson (2013) said in his article "Furniture for Later Life" that good furniture should be able to withstand wear and tear, cleaning, and washing. Wood is a highly recommended material for furniture, and it is believed to be a durable material that can provide both good quality and high aesthetics (Kamperidou, 2017). Besides the material, high-quality accessories and adhesives are both essential to make furniture strong and durable (2017). Cleaning is also one of the ways to maintain the long-term use of furniture, but too complicated and frequent cleaning work will cause a burden on users, so choosing materials with flat, smooth and easy to clean surfaces is more adequate for the people with mobility issues (Kamperidou, 2017; Lawlor & Thomas, 2008, p. 67).

All in all, ergonomic, properly dimensioned, safe, durable, and easy-to-clean furniture can accompany the user for a longer period and support the user's independent life, creating a safe, comfortable, and convenient living space for the user.

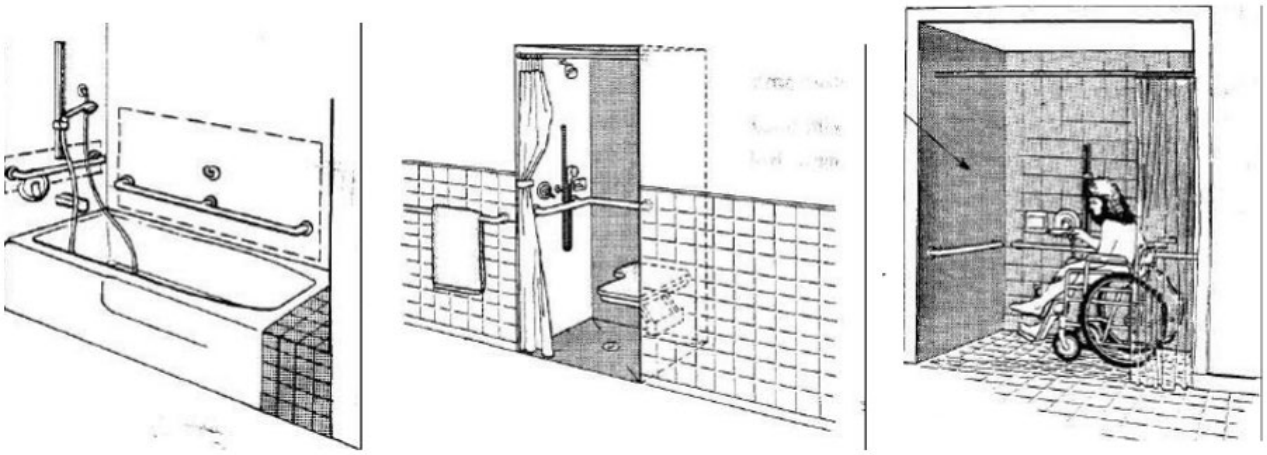
The following section will discuss in more detail choosing/designing appropriate furniture based on the different functionalities of the living space.

2.7.3 Bathroom

The bathroom is the most dangerous place in the room, especially for the elderly and disabled people. According to a survey by the American Journal of Public Health, the number of elderly people going to the hospital due to falls is five times higher than other reasons. Among

them, 20% to 30% of people suffer moderate to severe injuries due to falls, and even lead to death (Lawlor & Thomas, 2008) . Therefore paying more attention to furniture and materials to prevent the risk of people falling is crucial.

The bathroom can be divided into three main areas according to function: shower, toilet, and sink. For the shower area, in order to reduce the risk of falling, it is best to divide the bathroom into dry and wet areas. For people with mobility issues, there are three common bathing fixtures (Figure 29) that can be considered based on the user's different needs: tub with built-in transfer seat, transfer shower, and roll-in shower (Mace, 1991). A tub with a built-in transfer seat or surface provides a place for mobility impaired people to have a seat before entering the tub and provides a buffer area to avoid the risk of falling when stepping into the tub (Figure 30) (Mace, 1991, p. 151~154). The most obvious feature of the transfer shower is the L-shaped chair and L-shaped handle on the wall, which are used to help device users safely transfer into the shower room (1991). Figure 31 shows how wheelchair users use the transfer shower. Even for a normal walk-in shower, adding handles and seats can better avoid the risk of slipping. A roll-in shower is simply a waterproof area where wheelchair users can directly enter and take a shower on the wheelchair (Figure 32). Different from the normal walk-in showers, a roll-in requires a large space to facilitate wheelchair entry, and the raised strip at the entrance blocks the water flow while not affecting the entry and exit of wheelchairs (1991). Typical walk-in shower entrances often have a higher doorsill and a door which are not convenient for entry and exit. These three bathing fixtures may not be suitable for everyone, but adding adequate handles and seats to existing furniture is also a good solution.



(1) (2) (3)

Figure 29 Three common bathing fixtures (1) Tub with Built in Transfer Seat (2) Transfer Shower (3) Roll in Shower (Mace, 1991, p. 148)

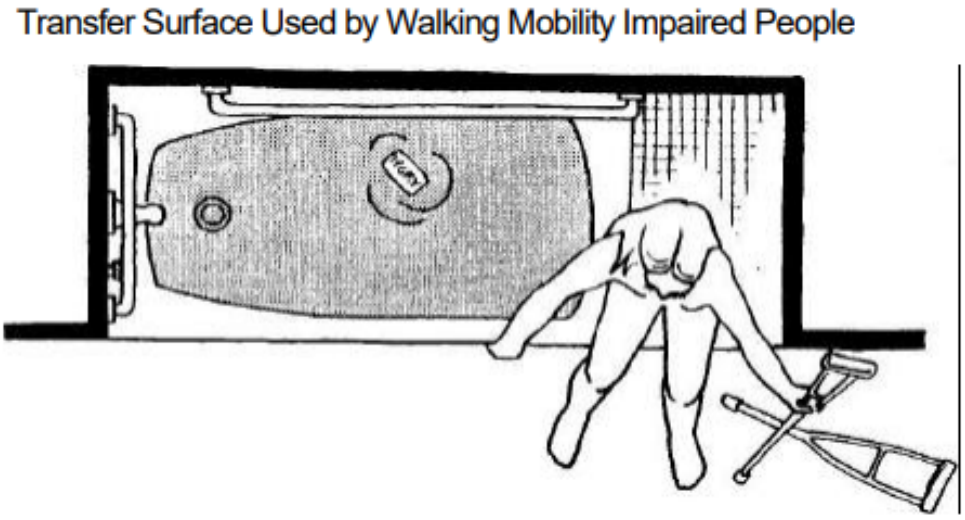


Figure 30 Transfer surface used by walking mobility impaired People (1991, p. 154)

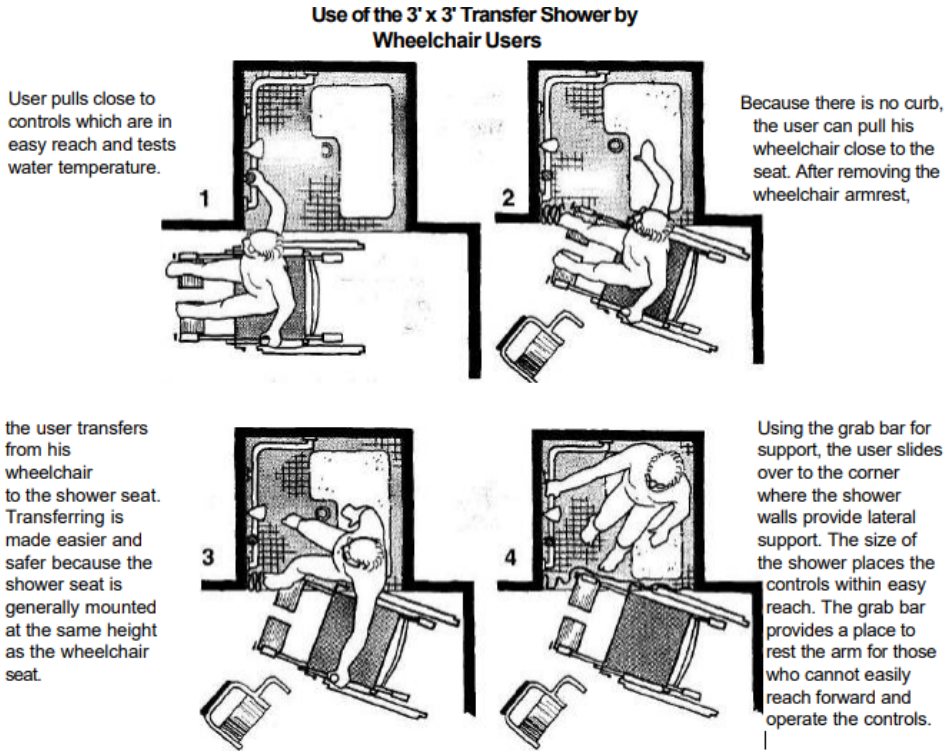


Figure 31 Wheelchair users use the transfer shower (1991, p. 165)

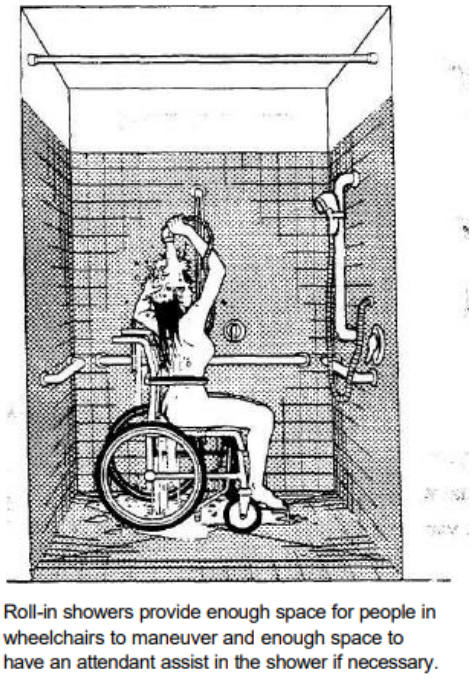


Figure 32 Wheelchair user uses the roll-in shower (1991, p. 167)

The two most common problems for people with mobility issues using the toilet are difficulty in squatting and standing up and transferring from/to the device. The height of a toilet directly affects the user's experience. High seats are better for people with difficult seat positions but can result in bad experience for shorter people because their feet cannot reach the floor; the low seat is hard for some mobility impaired people and aging people to stand up (Figure 33). Therefore, the height of the toilet should be determined based on the user's body dimension, needs, and the device used. According to the different transfer ways for wheelchair users from/to the toilet, designers should consider adding handles where appropriate to assist. Figure 34 lists the common wheelchair to toilet transfer techniques.

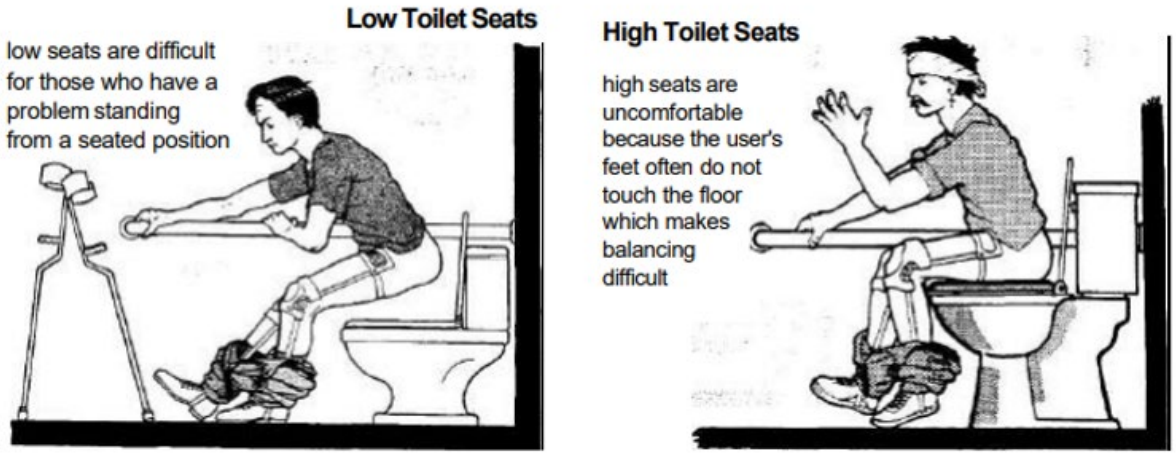


Figure 33 Different High of Toilet (Mace, 1991, p. 179)

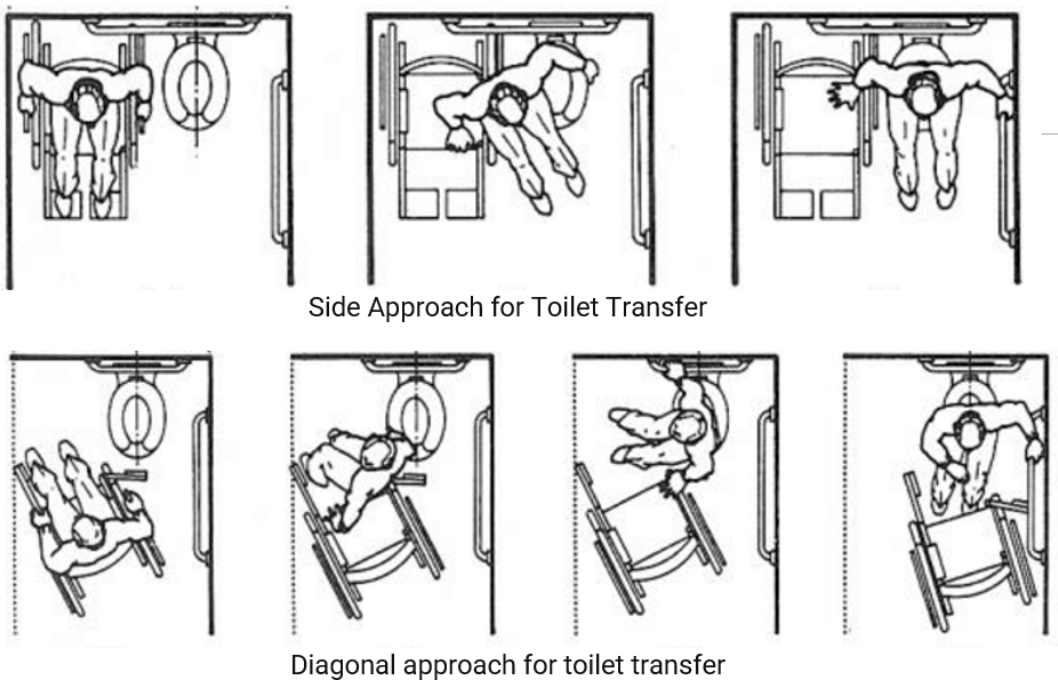


Figure 34 The common wheelchair to toilet transfer techniques (Ramachandran & Pugazhenthi, 2019)

The choice of sink mainly depends on the user's height and whether there is sufficient space; wall-mounted and countertop sinks are both good features for mobility impaired people (Mace, 1991). When designing and choosing a sink, it is recommended to use sturdy and easy-to-clean materials and it should have enough storage space to avoid users moving frequently. For wheelchair users, a space that can accommodate the knees is essential (Liu & Che, 2022).

In addition, for the bathroom entrance, sliding doors or doors that open outside (towards the hallway side) are recommended to prevent patients from blocking the entrance if they are in an emergency, making it difficult for rescuers to enter, or causing secondary injuries when entering (Lawlor & Thomas, 2008).

2.7.4 Kitchen

The kitchen is a highly functional space and is often the focal point of house design. The kitchen can generally be divided into a preparation area, cooking area and storage area. In order to create a practical, safe and comfortable kitchen for people with mobility impairments, designers need careful thought and planning. The standard kitchen work triangle (Figure 33) developed by University of Illinois' Building Research Council in 1949, is made by the sink, cooktop and the refrigerator (Lawlor & Thomas, 2008, p. 111). It is not a law or rule, but it can help designers to determine an efficient kitchen workspace. The storage area is the largest space in the kitchen. For people with mobility issues, traditional kitchen cabinet storage is not suitable for them, as they often encounter problems such as the cabinet location being too high to reach or too low to bend down (Mace, 1991). Therefore, designers need to choose appropriate storage furniture based on the individual situation.

Food-preparation is a time-consuming task that involves the use of sinks and working counters. For both the sink and working counter, heights and reach ranges are two important factors to determine the suitability for users to use. The counter and sink designed for wheelchair users should be lower than the general size and need to provide a clear knee space to facilitate their washing and cooking tasks (Mace, 1991).

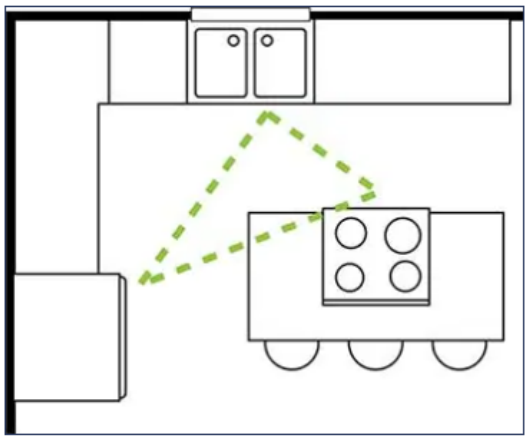


Figure 35 The Kitchen work Triangle (The Kitchen Work Triangle - Efficient Design & Traffic Patterns, n.d.)

Cooking is a dangerous task for anyone, let alone the elderly and disabled people with low flexibility and mobility. However, through thoughtful design the possibility of injury can be reduced. When choosing a cooktop, it is important to avoid those with rear controls which increases the chance of burning when reaching across pans or heated food, especially for shorter people and wheelchair users (Mace, 1991, p. 123) (Figure 36). The countertop cooktop is a great option for wheelchair users because it can be mounted at a lower position and provides enough under-knee room (Figure 38). The oven is an indispensable cooking equipment for many people, but common ovens are usually installed in a lower position, such as ovens in ranges, which is very inconvenient for people with limited mobility (Figure 39), and the drop-front door obstructs wheelchair users getting closer and limits the distance of reaching into the oven(1991, p. 124).

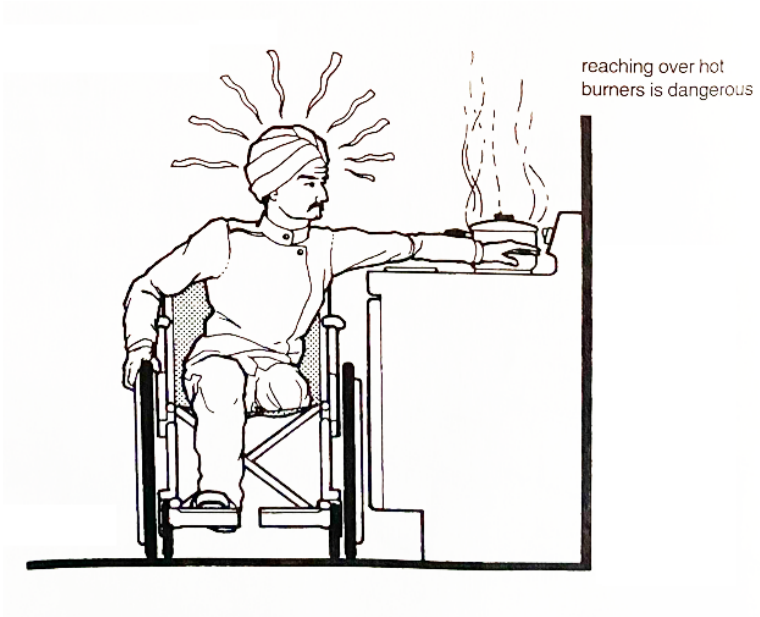


Figure 36 Cooktop with rear controls (Mace, 1991, p. 122)

Figure 37 Rear-control cooktop in apartment at Auburn.

Figure 38 The Countertop Cooktop (Adapted Kitchen Design for Wheelchair Users, n.d.)

Figure 39 Oven in range is difficult to use (Mace, 1991, p. 124)

No design can completely eliminate the occurrence of hazards. Users must be very careful while cooking to prevent dangers such as food and hot oil splashing, which can cause burns, fires, and other risks.

2.7.5 Bedroom

The bedroom is a place for people to sleep, relax and recover, so a comfortable bed and appropriate storage space will give people a better living experience. Although bedrooms have less functionality compared with bathrooms and kitchens, and there is rarely literature specifically talking about bedrooms, designing a comfortable bedroom for people with mobility issues also requires careful planning to facilitate their independent use. The size of the bedroom depends on the personal situation of the user (such as type of disability and device used), the type and amount of furniture (Mace, 1991, p. 192).

Beds are the most important furniture in the bedroom; a comfortable bed can help people eliminate the fatigue of the day. For people with limited mobility, the height of the bed directly affects the user's experience. A bed that is too high can make it difficult for the user to get on, while too low can bring more strain on their waist and lower limbs when sitting down (Yang et al., 2019). For wheelchair users, the biggest challenge is transferring between bed and wheelchair. According to two basic approaches to make independent transfers onto a bed - the lateral transfer and the forward transfer (Figure 40).

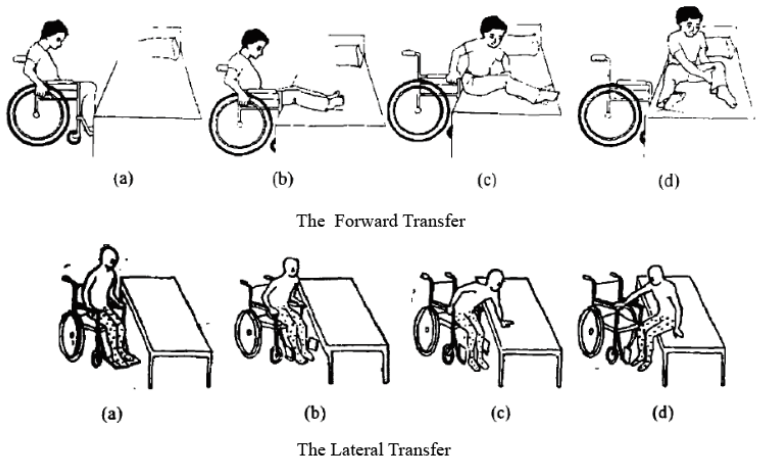


Figure 40 Two Basic Approaches to transfer onto a bed (Tian, 2003, p. 31)

Typically, tables of various functionalities can be used for most people. The only consideration is that wheelchair users require sufficient space under the table for their knees and enough clearance of the floor for turning and operation.

Most closets can be used by people with mobility issues, as long as doors are wide enough to allow wheelchair access. However, wide closets with narrow doors create dead areas that are hard to reach for many people with mobility issues (Figure 41) (Mace, 1991). Bi-fold and double doors are both good choices for closets because they provide a spacious and clear opening for easy entry and use (Mace, 1991, p. 202). Considering that the abilities of users may change over time (due to aging), closets with adjustable heights can be chosen for installation along with. The use modular systems on closet design allow shelves and clothes rods to be added, removed, or relocated by user requirements, which add versatility to the closet (1991, p. 207).

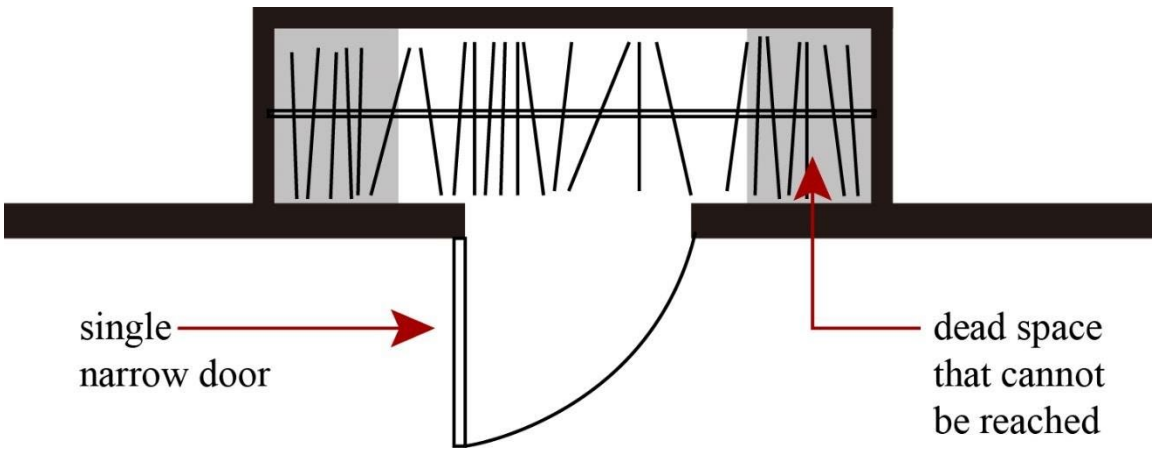


Figure 41 Wide Closet with Narrow Door (1991, p. 202) (re-draw by author)

Finally, considering that people may need to use the bathroom during the late night, the bedroom should be close to the bathroom with no obstacles in the way (Lawlor & Thomas, 2008).

2.7.6 Others

- **Doors**

Door openings need to be wide enough to allow users of devices such as wheelchair, walker, or crutches to pass through. The optimal door size should be a few inches wider than the mobility device, which give room for hands and arms, and provide necessary maneuvering space to pass through without bumping into the door frame (Mace, 1991, p. 70). Any raised panels can be snagged by mobility impaired people and make their passage difficult, so it is best to provide a full width panel at the bottom or use one panel doors for all entrances, if needed (Mace, 1991).

People who use walkers, wheelchairs, or crutches may have difficulty reaching the door handle to pull it closed, so designers should notice that. Sliding doors are sometimes used as closet doors, so if used the door assemblies should be good quality to reduce maintenance problem and risk, and it should be wide enough to use (Mace, 1991).

Door handles are also one of the parts that need to be paid attention to. Elderly people with limited mobility may have difficulty using traditional door handles, such as round knobs (Figure 42). There is a good test that determines the usability of a handle: if it is operable by using a clenched hand, it is a good handle (Mace, 1991, p. 75).

Figure 42 Round hand cannot operate by clenched hand (Shot by Author)

- **Windows**

A window that can be used by people with mobility issues must have the following three features (Mace, 1991, p. 91):

1. A clear floor space should be available at each window so a person can maneuver and get close enough to operate the window.
2. Window locks and operator within comfortable reach
3. Locks, operator, and window sash should be easy to open with one hand.

- **Sitting Furniture**

Sitting Furniture is an indispensable type of furniture in a house, even for those in wheelchairs. They also need chairs, sofas, or other types of sitting furniture. According to the research, 67% of elderly were sedentary for more than eight and a half hours a day (Fabisiak et

al., 2021), and being sedentary is a common state for people with mobility issues. Therefore, good sitting furniture should be comfortable, safe, and high quality.

It is very important to choose/design sitting furniture based on personal body dimensions. A chair that is too high can prevent shorter people's feet touching the ground, while a seat that is too deep can make it difficult to get up (Fabisiak et al., 2021). The armrests of seats are very necessary and should be sturdy to provide support for people with mobility issues and help them sit down and stand up (Kamperidou, 2017).

The above are common problems that need to be considered when designing/selecting furniture for people with mobility issues. Safety should always be the primary consideration, followed by usability and comfort. The text also mentions adjustable furniture and modular closets, indicating that modular design in living space can provide a more flexible and convenient living environment for users' independence.

2.8 Modular Design in Furniture

2.8.1 What is Modular Design?

Modular Design works through breaking down an entire design into multiple consistent "modules" based on different functional and structural themes with consistent (standardized) interfaces, and users can combine different modules to build a design that achieves their individual needs (Gonzáles-Vega, 2015; Wang, 2022; Zhou et al., 2021). The advantage of Modular Design is that it can be low-cost, easy customizable, and have the capacity to quickly respond to market and user changes by adding and replacing modules (Wang, 2022).

2.8.2 Modular Furniture Design

Modular Furniture Design is based on analyzing the functions of furniture and then dividing and designing a series of modules, as well various types of furniture that can be combined by selecting different functional modules to meet the diverse needs of users (Zhang, 2020).For example, a closet can be divided into modules such as the main cabinet, shelves, drawers, and rods, which can be selected, combined, or removed based on the user's needs and their body dimensions.

2.8.3 4 Basic Levels in Modular system

When using modularity in the development of new products, modular system designers need to design and specify a design rule that may occur at four different levers (Mikkola, 2000), see Figure 43:

- Components: parts standardized, well defined, and accepted as industry standards.
- Module: Combination of different parts of the component level.
- Subsystem: formed by the combination of modules.
- System: Composed of subsystems with clear boundaries and defined interfaces.

Still using the closet as an example, components are standard hardware, such as screws; shelf, drawer, and rod are modules; using the different modules combined with shelf area, drawer area and hanging area are the different subsystems; those subsystems make up a complete closet which is a system.

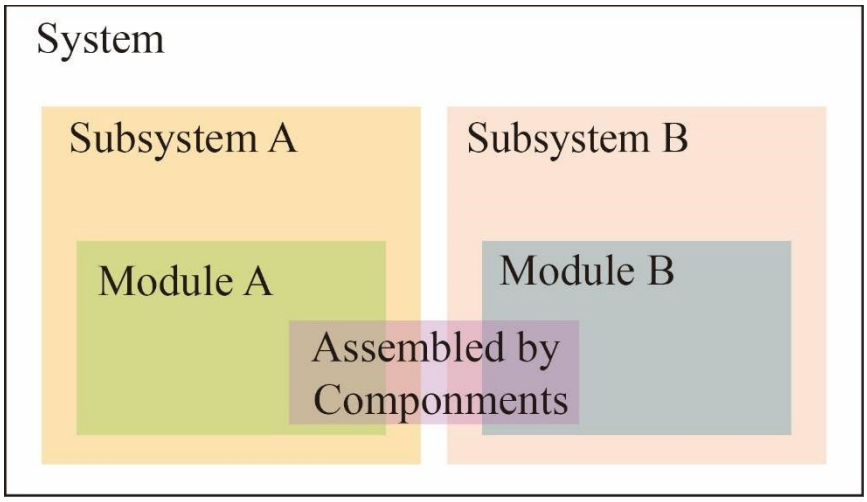


Figure 43 Modularity Levers

2.8.4 How to Divide Modules for Furniture?

The foundation of modular design is based on the division of modules. The division directly impacts the functionality of the furniture and the user experience. Therefore, the division of modules requires careful consideration by designers. More modules do not mean a better product because of the number of modules can affect the complexity of the overall system (Gonzáles-Vega, 2015).

First and foremost, it is essential for designers to communicate with users, understand their needs and translate them into functional requirements. Next, they need to divide the product functionally by users' need, and determine the modules and subsystems (Du, 2020). When dividing furniture modules, it is necessary to consider standardization (for mass-produced items), specificity (for individually produced items), ease of assembly and convenience of use.

2.8.5 Benefits of Modular Furniture for People with Mobility Issues

Based on the characteristics of modular furniture, users can combine the different modules according to their preferences and needs that come out with the furniture which is the

most appropriate to them. It can effectively respond to the diversity and particularity of the target group. Moreover, modular furniture design uses consistent interfaces to facilitate assembly, disassembly, and modification to cope with changes of the user's body condition. Compared to the modification of normal furniture, the renovation of modular furniture can be faster, as it does not require complete dismantling and reassembling of the whole furniture, only needing an upgrade and replacement of the modules, so it can reduce the cost of money and time.

Therefore, the sensible application of modular design for people with mobility issues can not only meet their current life needs, but also facilitate future modifications according to changes in their personal body states, thereby improving the user's quality of life and independence.

2.9 Conclusion

In this chapter, the author discusses the importance of independent living for all people and realizes the diversity of target users. It has been found that the design concept of "DESIGN FOR EVERYONE" does not apply to everyone. This article advocates investigation and analysis of individual users based on the information and data obtained from the research (including body size measurements, devices used and individual needs) to design. This chapter also discusses the application of modular design to living environment can effectively help people with mobility issues improve their independence.

Therefore, Chapter 3 will provide designers with a design approach that guides designers to start from understanding user needs and user body data, to how to plan space reasonably, design/choose home fixture and furniture, and then combine modular design according to user preferences, ultimately designing a comfortable, convenient and safe independent living environment.

Chapter 3 Design Approach

Chapter Three will develop the design approach which can give designers some references to create a customized independent living environment for people with mobility issues based on the literature review, research, and author's analysis. This approach adheres to user-centered design methodology, starting with understanding user requirements and knowing body dimensions which is a foundation throughout the whole design process. The following approach includes space planning, how to design or choose home fixture and furniture, and the application of modular design.

Before applying this approach, it is necessary to thoroughly understand relative standards, law, and regulations, such as ADA Standards (Americans with Disability Act) and ANSI (American National Standards Institute) relevant standards. The data/dimensions in this approach are modified based on the ADA Standards and ANSI frameworks according to user's personal status, which is not appropriate to commercial properties, rental houses, or any non-personal/commercial spaces.

The purpose of this approach is to design a comfortable, convenient and safe living space that promotes independence for people with mobility issues.

3.1 Know the User

Understanding the user is the foundation of all design, so the first step in this design approach is to comprehend the user's specific difficulties and needs.

3.1.1 User Research Form

In Chapter 2, the thesis introduces several daily life assessment forms as tools for evaluating people's level of independence in daily activities. These tools list various daily activities and use a scoring system to determine the user's level of independence. Clearly, the scoring way does not apply to this study, but the author found it is an effective method to understand user needs by filling out the form. Therefore, to gain a more systematic and comprehensive understanding of the different challenges each user encounters in their daily independent living, the author has created a user research form. By having users fill out this form, designers can have a basic understanding of user needs and help clarify the direction for subsequent designs. The form is divided into three sections, which are the basic information section, problems survey section, and additional comments section.

In addition to the usual information such as name, gender, and age, the basic information section includes more relevant questions about the user group of this guideline, such as "Do you use any mobility devices?" and "Do you have any impairments?". Understanding whether users have mobility devices and which devices they use can better allow the designer to analyze the reasons for their difficulties and prepare for later collection of user body data.

The problems survey section is divided into five main areas based on different functions: Entrance, Bathroom, Bedroom, and Kitchen. Each area lists the use of furniture involved in this area and asks users to indicate whether they have difficulties using that furniture and to describe the specific difficulties they encounter. This part of the research aims to identify the real issues

users face in their daily lives and to address these issues more specifically, correctly, and effectively in the subsequent design phase.

The final section is for additional comments. To understand the diverse needs of users, designers or users can add any difficulties, or anything not covered in the form that troubles them in independent life or list their personalized requirements. Those information will help design a more practical, convenient, and comfortable living space in later design processes

Table 1 User Research

User Research		
Name:	Gender:	Age:
Do you use any mobility devices? ☐ Yes ☐ No If yes, which one do you use:		
Do you have any:	☐ Hearing Impairment ☐ Speech Impairment ☐ Visual Impairment ☐ Others:	

Entrance	With ease	With difficulty	Explanation
Main Door Pass Through	☐	☐	
Bedroom Door Pass Through	☐	☐	
Bathroom Door Pass Through	☐	☐	
Others	☐	☐	

Bathroom	With ease	With difficulty	Explanation
Transfer Toilet	☐	☐	
Transfer Show/Tub	☐	☐	
Toilet Use	☐	☐	
Shower/Tub Use	☐	☐	
Sink Use	☐	☐	
Others	☐	☐	

Bedroom	With ease	With difficulty	Explanation
Transfer Bed	☐	☐	
Bed Use	☐	☐	
Table Use	☐	☐	
Closet Use	☐	☐	
Others	☐	☐	

Kitchen	With ease	With difficulty	Explanation
Cooktop Use	☐	☐	
Sink Use	☐	☐	
Counter Use	☐	☐	
Storage Use	☐	☐	
Appliances Use	☐	☐	
Others	☐	☐	

Other problems/obstacles/:
Additional Requirements:

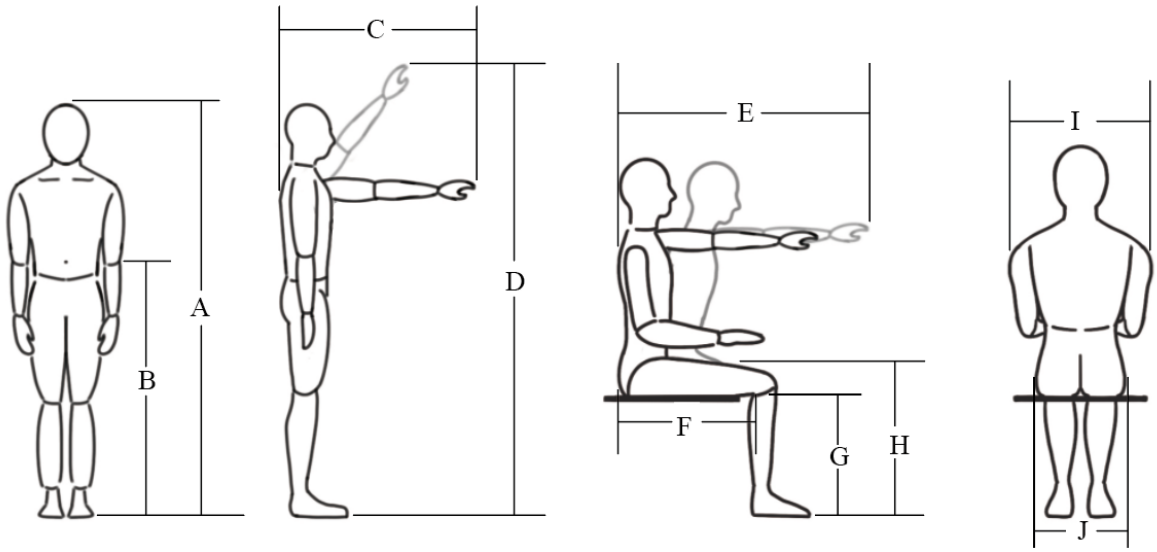
3.2 Data Collection

In the second chapter, it was mentioned that anthropometry is a highly specialized and complex discipline, where incorrect measurement methods can make data ineffective. Body measurements can vary significantly based on gender and age. Therefore, the author has compiled various anthropometric data, organizing it into five tables for ease of access, categorized by age, gender, and mobility status (use of wheelchair or not).

Prior to 1993, designers primarily focused on the 5th, 50th, and 95th percentiles of body dimensions. However, for more inclusive design, Henry Dreyfuss updated his book in 1993, enriching the data and advocating for designers to consider the 1st, 50th, and 99th percentiles (Herwig, 2008). Thus, data for non-wheelchair users is divided into four tables, recording the 1st percentile, mean, and 99th percentile data according to age and gender. Due to the limited data available for wheelchair users, only the 5th, 50th, and 95th percentiles are available.

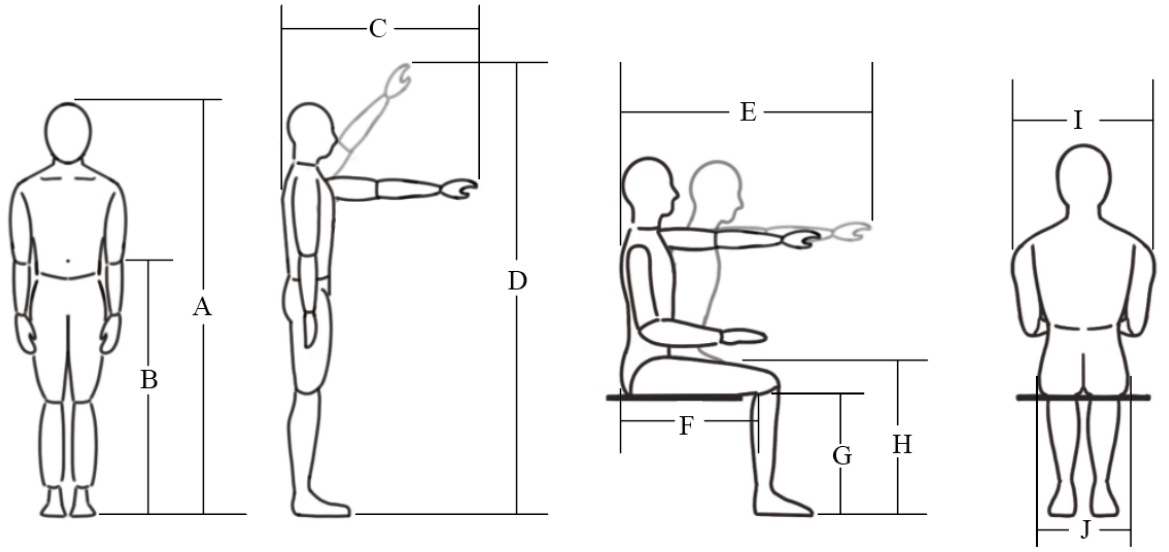
3.2.1 Age 18~65 Male Anthropometric Data

Table 2 Age 18~65 Male Anthropometric Data

Age 18~65 Male Anthropometric Data (up to 240lb), Inches				
Name:		Age:	Height:	
				
	Measurement	1st	Mean	99th
A	Stature	60.3	69.1	75.6
B	Elbow Height	37.87	42.2	46.62
C	Functional Grip Reach	26.48	29.51	33.08
D	Vertical Grip reach	74.52	82.91	91.07
E	Functional Grip Reach, Extended	28.69	32.2	36.11
F	Buttock-popliteal Length	17.37	19.67	22.21
G	Popliteal Height	16.5	18	19.5
H	Knee Height	19.55	21.95	24.54
I	Shoulder Breadth	15.8	18.3	20.6
J	Hip Breadth (Sit)	11.4	14.2	16.9
Both non-device users and standing device users can refer to the above data.				
Data Source: The measure of man and woman (Dreyfuss, 1967); Anthropometric Data (Jahoyle, 2006) .				

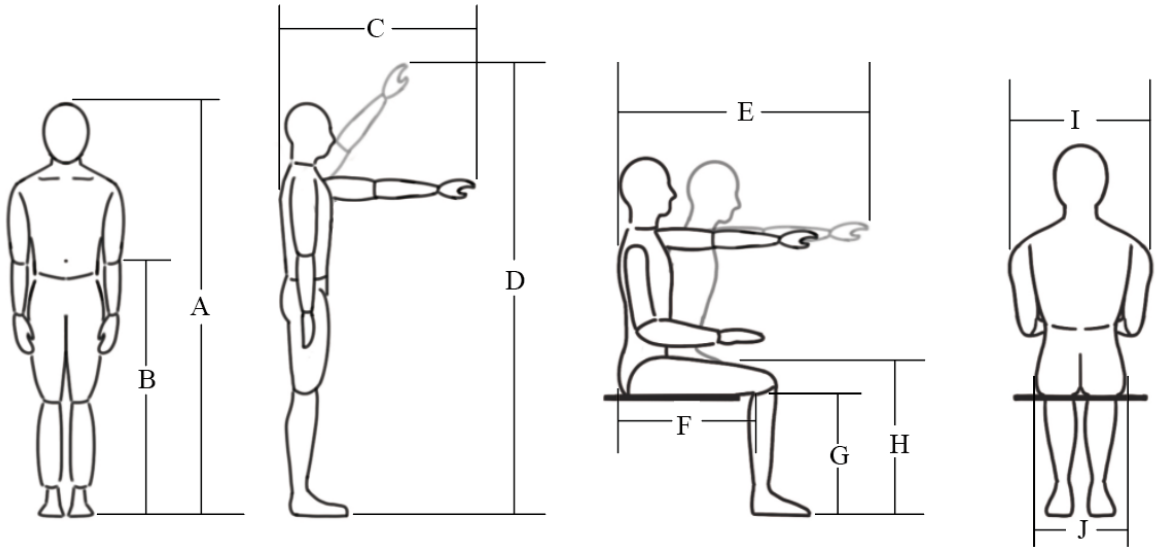
3.2.2 Age 18~65 Female Anthropometric Data

Table 3 Age 18~65 Female Anthropometric Data

Age 18~65 Female Anthropometric Data (up to 217lb), Inches				
Name:		Age:		Height:
				
	Measurement	1st	Mean	99th
A	Stature	58.1	64	70.09
B	Elbow Height	35.24	39.24	43.65
C	Functional Grip Reach	24.22	26.97	30.3
D	Vertical Grip reach, Height	68.75	76.57	84.64
E	Functional Grip Reach, Extended	26.2	29.32	32.87
F	Buttock-popliteal Length	16.5	19.2	21.1
G	Popliteal Height	15	16.5	17.5
H	Knee Height	17.3	19.2	22.75
I	Shoulder Breadth	13.5	16.1	18
J	Hip Breadth (Sit)	11.2	14.6	18.3
Both non-device users and standing device users can refer to the above data.				
Data Source: The measure of man and woman (Dreyfuss, 1967); Anthropometric Data (Jahoyle, 2006) .				

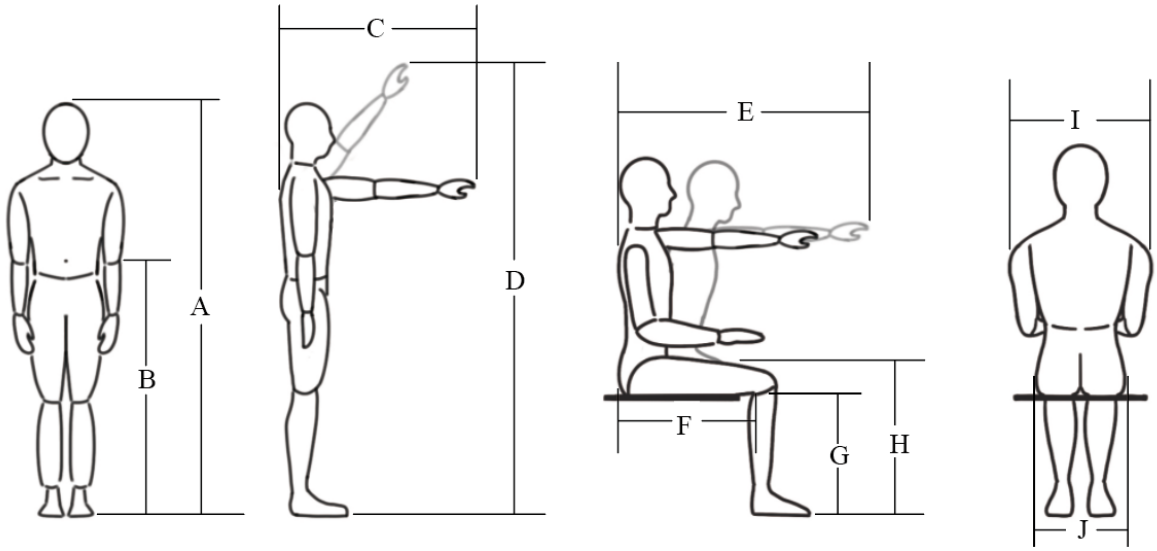
3.2.3 Age 65 Above Male Anthropometric Data

Table 4 Age 65 and Above Male Anthropometric Data

Age 65 Above Male Anthropometric Data (up to 226lb), Inches				
Name:		Age:	Height:	
				
	Measurement	1st	Mean	99th
A	Stature	59.3	65.8	71.8
B	Elbow Height	36	40.6	44
C	Functional Grip Reach	21.7	26.2	28
D	Vertical Grip reach	66.9	73.9	78
E	Functional Grip Reach, Extended	n/a	n/a	n/a
F	Buttock-popliteal Length	16.8	19	21
G	Popliteal Height	15.5	17.5	19
H	Knee Height	18	20.1	23.4
I	Shoulder Breadth	15.4	17.1	18.9
J	Hip Breadth (Sit)	11.9	15.2	18
Both non-device users and standing device users can refer to the above data.				
Data Source: The measure of man and woman (Dreyfuss, 1967); Anthropometric for Elderly (Kothiyal & Tettey, 2001)				

3.2.4 Age 65 Above Female Anthropometric Data

Table 5 Age 65 Age 65 and Above Female Anthropometric Data

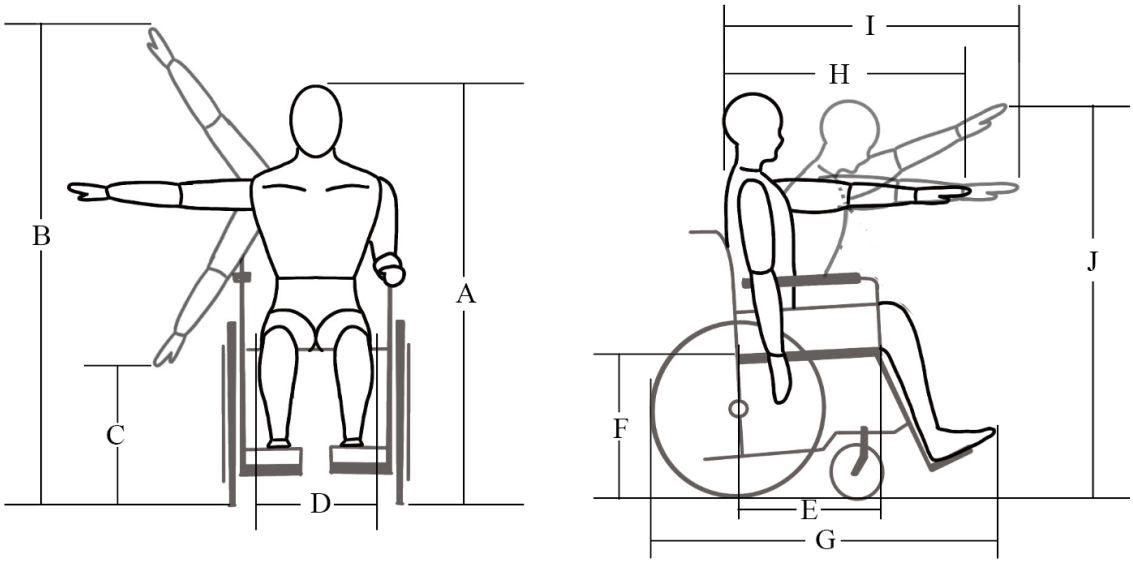
Age 65 Above Female Anthropometric Data (up to 217lb), Inches				
Name:		Age:	Height:	
				
	Measurement	1st	Mean	99th
A	Stature	56.8	61.6	66.5
B	Elbow Height	34.3	37.9	41.5
C	Functional Grip Reach	21.7	25.6	28
D	Vertical Grip reach, Height	58	69.2	75
E	Functional Grip Reach, Extended	n/a	n/a	n/a
F	Buttock-popliteal Length	16.3	18.9	21.1
G	Popliteal Height	14.3	16.4	18.5
H	Knee Height	16.9	18.6	20.5
I	Shoulder Breadth	13.1	15.9	17.6
J	Hip Breadth (Sit)	12.9	15.7	18.6
Both non-device users and standing device users can refer to the above data.				
Data Source: The measure of man and woman (Dreyfuss, 1967); Anthropometric for Elderly (Kothiyal & Tettey, 2001)				

3.2.5 Age Above 20, Wheelchair User Anthropometric Data

Table 6 Age Above 20, Wheelchair User Anthropometric Data

Age Above 20, Wheelchair User Anthropometric Data, Inches

Name: Age: Seat Height:



	Measurement	5th	Mean	95th
A	Seated Stature	40.5	54.7	60
B	Max. Side Grip height	51	62	n/a
C	Min. Side Grip height	n/a	4.7	7.2
D	Hip Breadth	13.7	15.6	18
E	Buttock-popliteal Length	17	19	21
F	Seat Pan Height	15	18.1	22.1
G	Overall Length	36	44.3	47.8
H	Arm Reach Depth	22.5	24.8	27.1
I	Max. Side Reach Depth	30.6	33.5	36.5
J	Max. Forward Grip height	40	48.5	55.7

ADA and ANSI have clear regulations for the common dimensions needed by wheelchair users. The above dimensions are only used to narrow down the range of values or for those without specific measurements.

Data Source: The measure of man and woman (Dreyfuss, 1967); Structural anthropometric measurements for wheelchair mobile adults (Das & Kozey, 1999).

3.3 Spacing Planning

Table 7 Space Research & Design

Space Research & Design		
Name:	Date:	
Location	Main Entrance ☐ Kitchen ☐	Bathroom ☐ Bedroom ☐
Length:	Width:	Height:
Current Plan		
Plan After Design/Redesign		

This form is primarily divided into two parts. The first part is surveying the area that needs to be designed, which should be completed before starting space planning. The second part is filled out after completing space planning (not necessarily to be the final version). The author combines these two parts in one form for several reasons: on the one hand, it facilitates designers in confirming information and data; on the other hand, it makes communication with users easier. Comparing before and after can more clearly articulate the design's purpose and reasoning and allow for timely adjustments based on user feedback.

3.3.2 Clear space

In the 2010 ADA Standards for Accessible Design, Section 305.3 specifies that a clear floor/ground space shall be a minimum of 30 inches by 48 inches. Clear floor spaces should be positioned to allow for either a forward or parallel approach to an object and at least one side must be adjacent to or overlap with an accessible route (ADA, 2010), as shown in Figure 44.

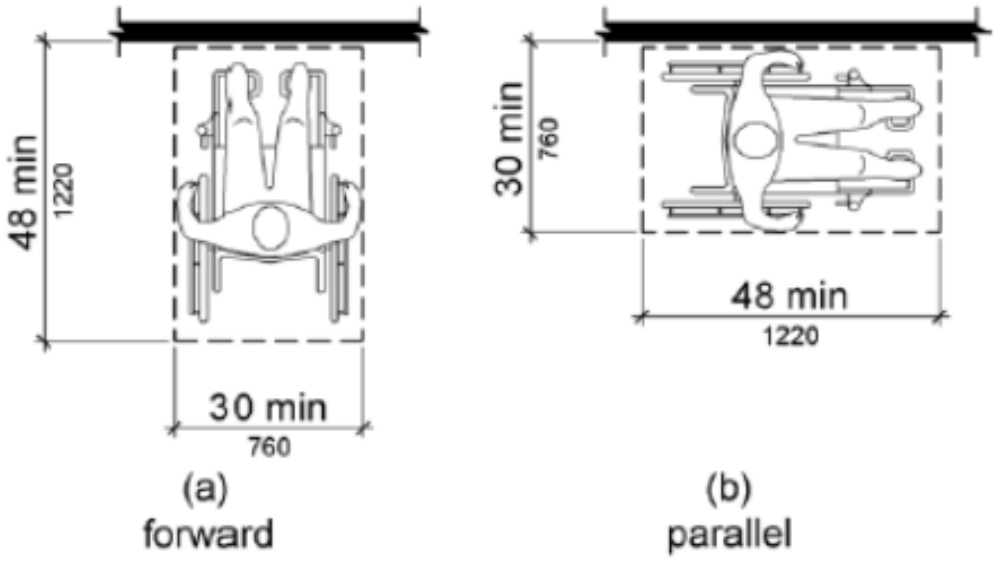


Figure 44 Position of Clear Floor (ADA, 2010)

3.3.3 Turning Space

Turning space may not be as crucial for users of small mobility devices, but it is an important space for wheelchair users to ensure comfortable and safe use of their device. Turning space is typically discussed in two types: circular space and T-shaped space.

The ADA standards, in section 304.3, specify: “The turning space (circular space) shall be a space of 60 inches diameter minimum. The space shall be permitted to include knee and toe clearance” (2010).

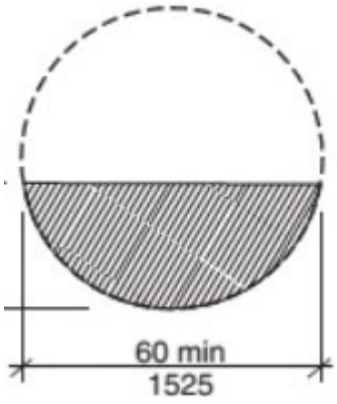


Figure 45 The turning space (ADA, 2010)

The T-shaped turning space is the minimum configuration used to allow turning when there isn't enough room for a full 360-degree turn, as Figure 46 shows. T-shaped space within a 60 inches square minimum with arms and base having 36 inches wide minimum, each arm should be clear of obstructions for 12 inches and the base should be clear of obstructions for 24 inches (2010, sec. 304.3).

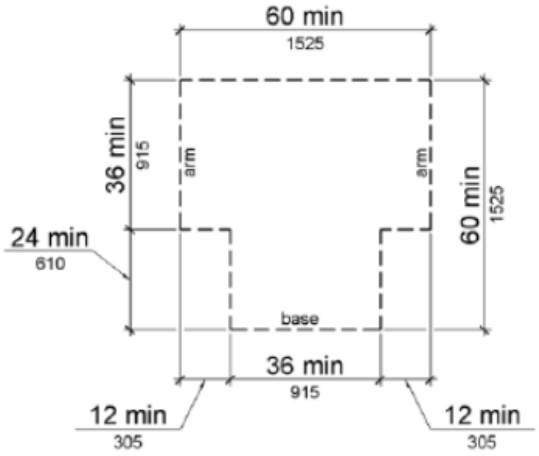


Figure 46 T-shaped turning space (ADA, 2010)

3.3.4 Knee Clearance & Toe space

Knee space and toe space are specific areas designed to accommodate wheelchair users or others who use seated mobility devices. When designing furniture for wheelchair users, it is necessary to provide at least 27 inches of height by 30 inches of width for knee space, and a minimum of 9 inches in height with a depth ranging from 17 inches to 25 inches maximum for toe space (ADA, 2010, sec. 306.3).

If the user does not use a wheelchair or other seated mobility devices, and there is no consideration of future needs for such accommodations, providing this space may not be necessary.

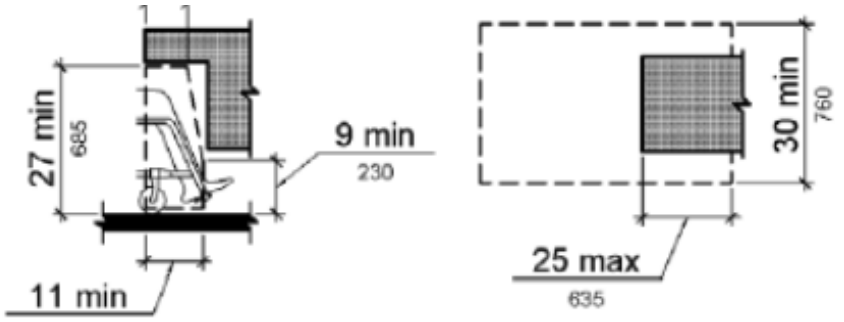


Figure 47 Knee space and toe space (ADA, 2010)

3.3.5 Passage

According to ADA standards, the minimum clear width for passageways must be at least 36 inches (2010, sec. 403.5). This width is generally suitable for users of most mobility devices (see Figure 48) . However, there is an exception for users of crutches. Depending on individual walking styles and usage habits, these users may require wider passageways. In such cases, as depicted in the illustration, the passageway can be widened to 48 inches to accommodate easier movement (see Figure 49). Nonetheless, when space is limited, a width of 36 inches is still permissible and can be used effectively.

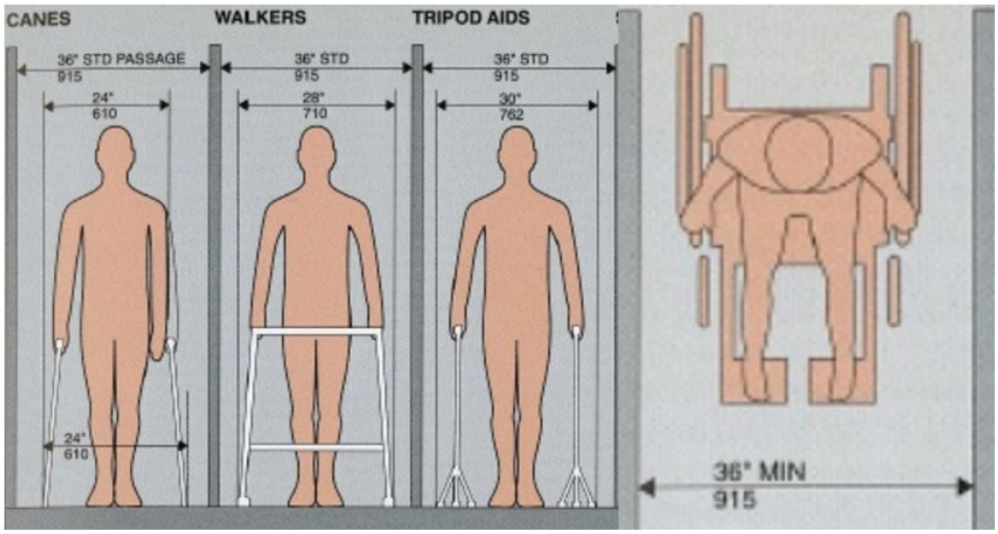


Figure 48 Passage for canes, walkers, tripod aids and wheelchair users (Dreyfuss, 1967)

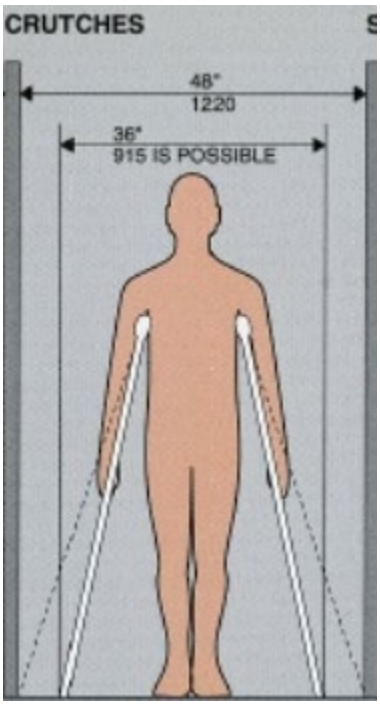


Figure 49 Passage for crutch user (Dreyfuss, 1967)

3.3.5 Entrance Space Planning

For users of mobility devices, the most appropriate minimum doorway width is 36 inches (Panero & Zelnik, 1979). However, for spaces with limited room or for users who do not use a mobility device, the minimum doorway width can be reduced to 32 inches.

Additionally, users of mobility devices require adequate maneuvering space to push or pull the door. On the pull side of the door, there must be at least 60 inches of space perpendicular to the doorway, and an additional minimum width of 18 inches. On the push side, the required space is a minimum of 48 inches perpendicular to the doorway.

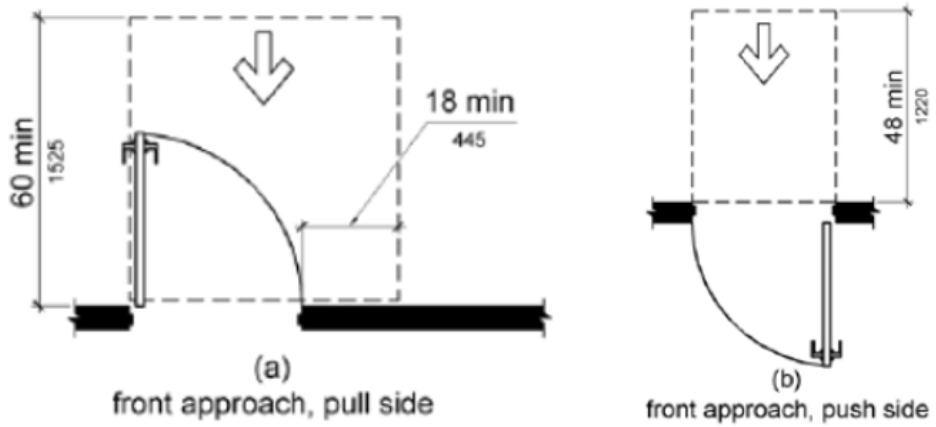


Figure 50 Clear space for doorway (ADA, 2010)

3.3.6 Bathroom Space Planning

The position for toilet is best with walls on the rear and one side, and the centerline of the toilet should be 16 inches (minimum) to 18 inches (maximum) from the side wall (ADA, 2010, p. 604.2), see Figure 51. The minimum clear floor space at toilets is 60 inches (measured perpendicular from the side wall) by 56 inches (measured perpendicular from the rear wall) (ADA, 2010, sec. 604.3). If the user does not use a wheelchair and there is no consideration for the potential future use of a wheelchair, it is not necessary to comply with this specific regulation. Instead, the minimum clear space needs to be provided.

For standard bathtubs, the ADA (2010) specifies that the required clearance must be at least the length of the bathtub and a minimum of 30 inches in width. If the bathtub is equipped with a built-in seat, the clearance must extend a minimum of 12 inches beyond the end of the bathtub (sec. 607.2). This additional space is necessary to accommodate the transfer from a mobility device to the bathtub seat, ensuring that users can access the seat safely and comfortably.

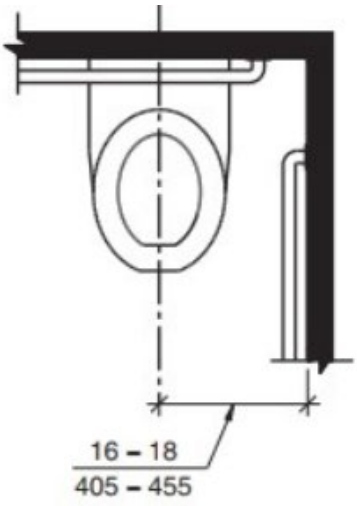


Figure 51 Toilet Position (ADA, 2010)

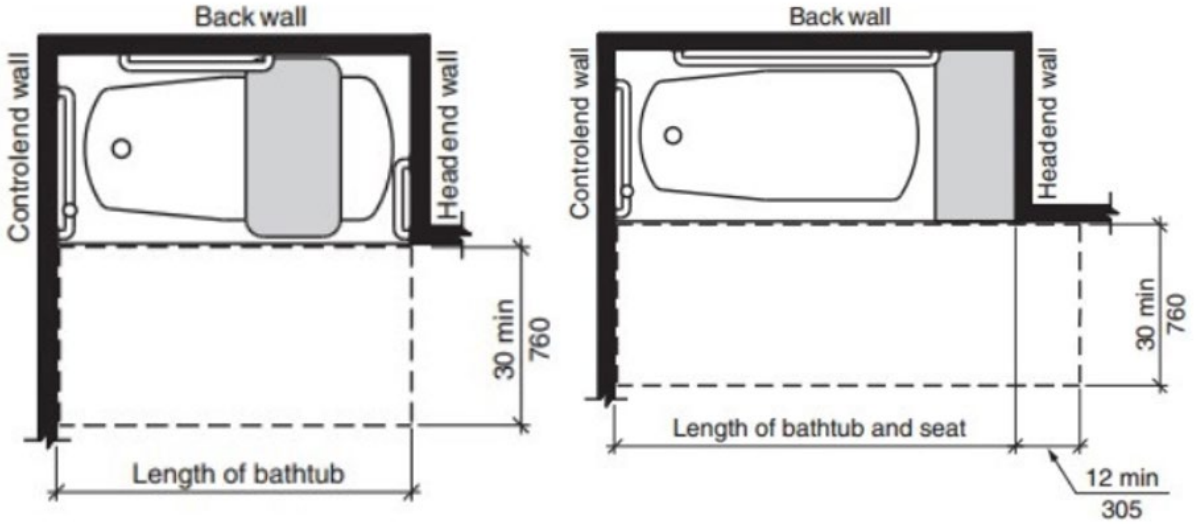


Figure 52 Clear space for bathtub (ADA, 2010)

For users who prefer a transfer shower, the interior dimensions of a standard transfer shower must be 36 inches by 36 inches, with an entrance that is no less than 36 inches wide. Additionally, there must be at least 36 inches wide by 48 inches long of clearance outside the shower (ADA, 2010, sec. 608.2).

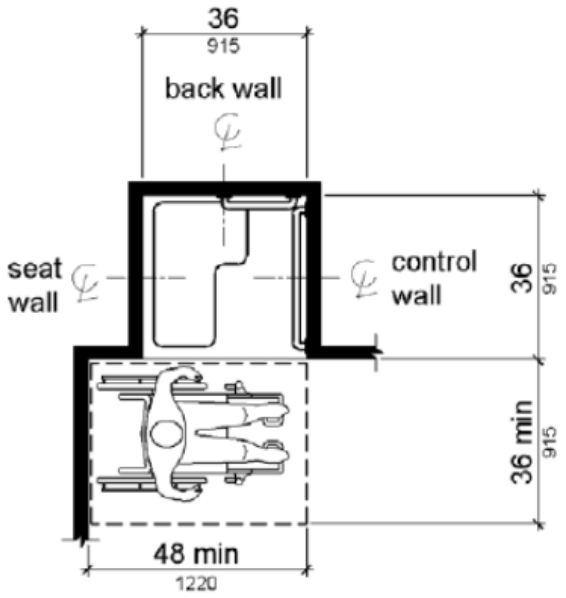


Figure 53 Transfer shower required dimension (ADA, 2010)

For those opting for a roll-in shower, the standard roll-in type shower must have a minimum internal space of 30 inches in width by 60 inches in length. Moreover, it requires at least 30 inches of width and 60 inches of length for clearance near the shower to accommodate the movement of wheelchairs and other mobility devices (ADA, 2010, sec. 606).

Regarding the clear floor space in front of a sink, ADA (2010) standards require that it must be positioned for a forward approach (sec. 606). For wheelchair users, this area must also include knee space to allow close access to the sink without obstruction.

3.3.7 Kitchen Space Planning

Both ANSI and ADA categorize kitchens into two types: pass-through kitchens and U-shaped kitchens. In a pass-through kitchen, where counters, appliances, or cabinets are on two opposing sides, the clearance between them needs to be at least 40 inches (ADA, 2010, sec. 804.4), see Figure 54. For the common U-shaped kitchen, which is enclosed on three contiguous sides, the clearance between all opposing items shall be a minimum of 60 inches (804.2).

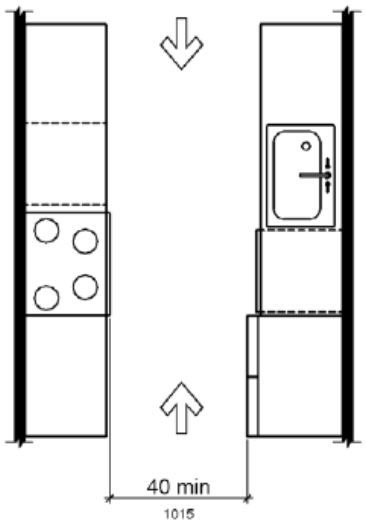


Figure 54 Pass-through kitchen (ADA, 2010)

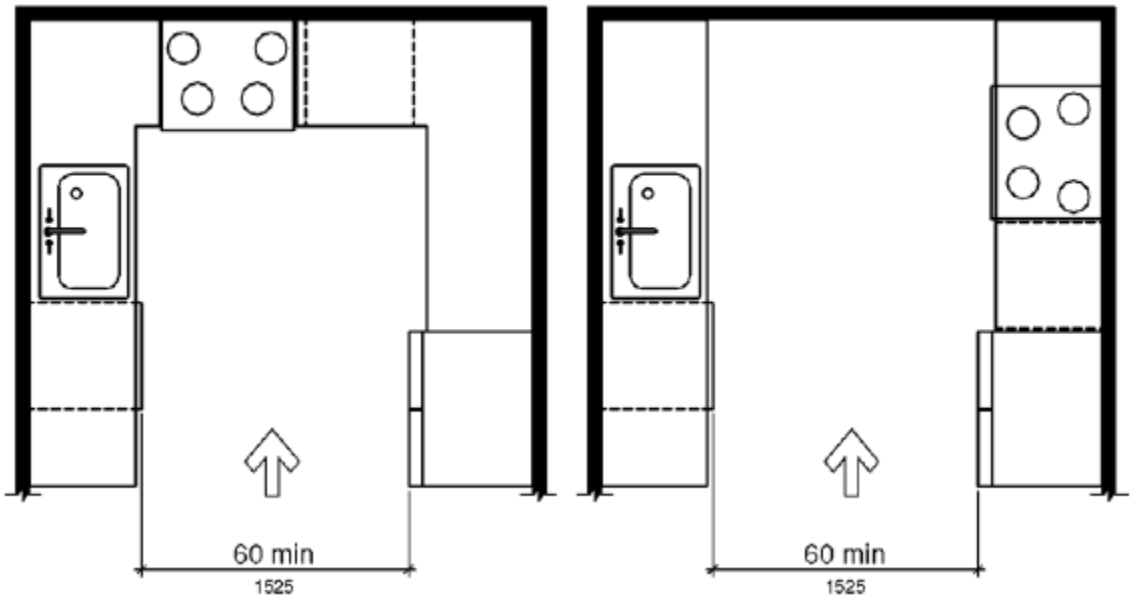


Figure 55 U-shaped kitchen (ADA, 2010)

Besides the pass-through space, standards also specify that all fixtures that require operation, such as sinks, dishwashers, ovens, and cooktops, must provide space accessible for a forward or parallel approach (ADA, 2010, p. 3.3.1). For wheelchair users, these areas must also include adequate knee space to facilitate ease of use. When planning the layout, it's beneficial to

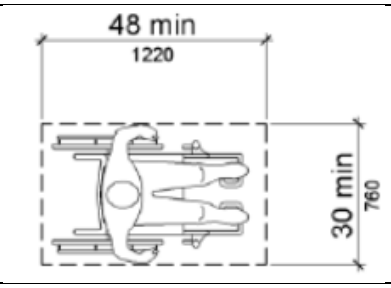
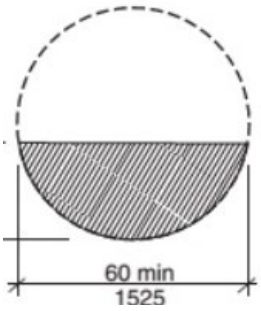
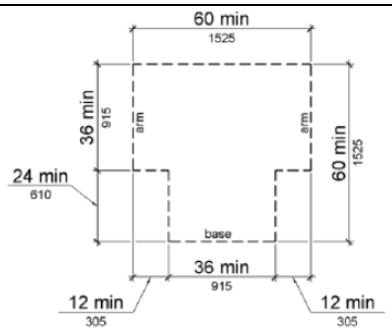
consider the application of the "kitchen work triangle" concept, which helps in optimizing the placement of the sink, refrigerator, and stove/oven for efficient use of the kitchen.

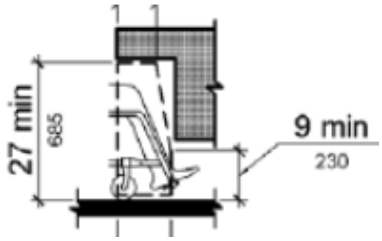
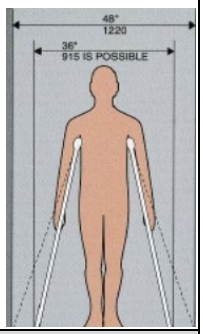
3.3.8 Bedroom Space Planning

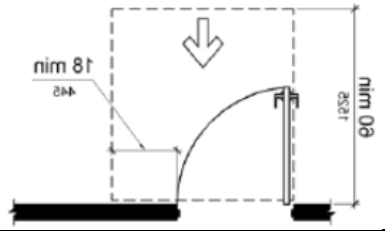
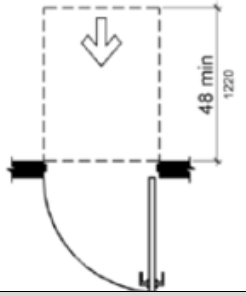
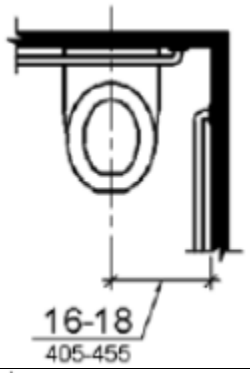
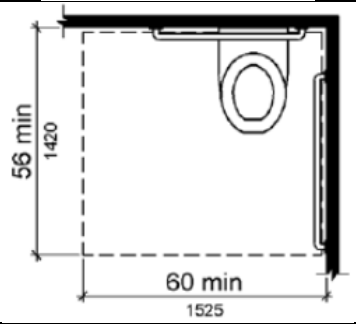
While the ADA and ANSI do not have specific regulations for bedrooms, insights can be gleaned from other spaces and related literature to identify useful guidelines. In the book "*The Accessible Housing Design File*," it is mentioned that there should be at least 36 inches of clear space around the bed for accessibility, but 42 inches is preferable for easier maneuverability of devices. Desks or tables should provide a forward approach space, which may include space under the table for knees. Bedside tables, cabinets, and windows should offer either a forward or parallel clear approach space (Mace, 1991). Closet doors should ideally adhere to ADA standards for doorways, which require a minimum width of 36 inches.

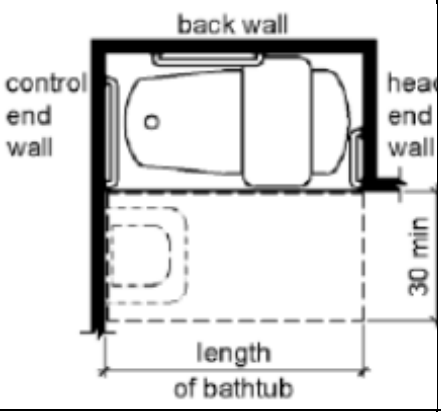
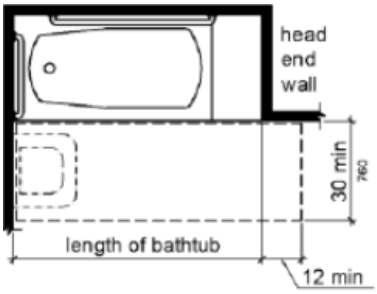
3.3.9 Space Planning Dimension Check List

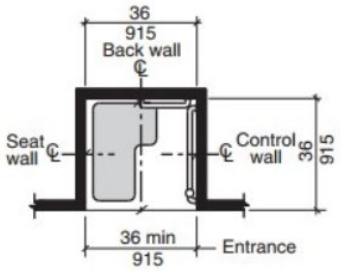
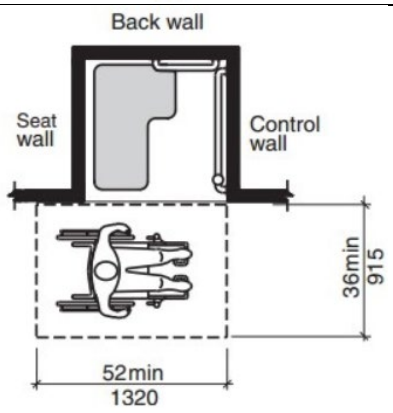
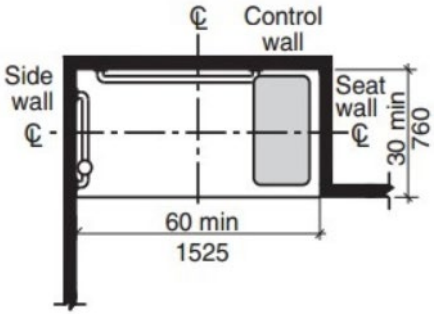
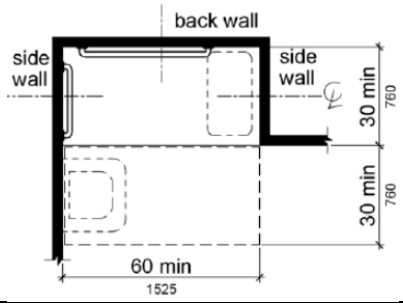
Table 8 Space Planning Dimension Check List

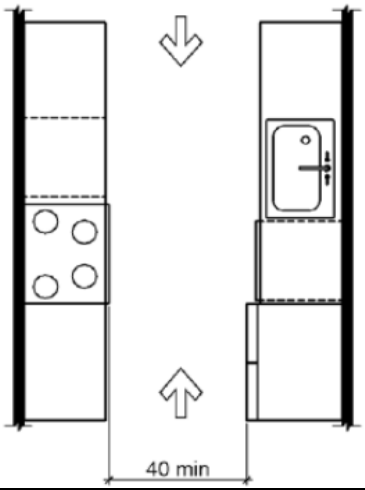
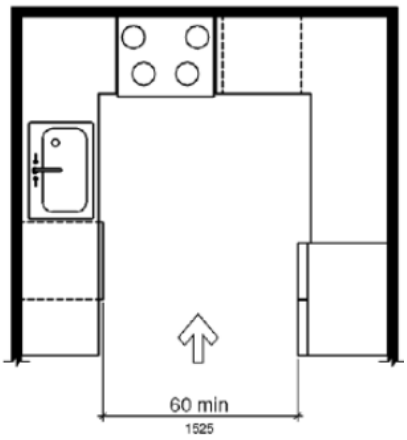
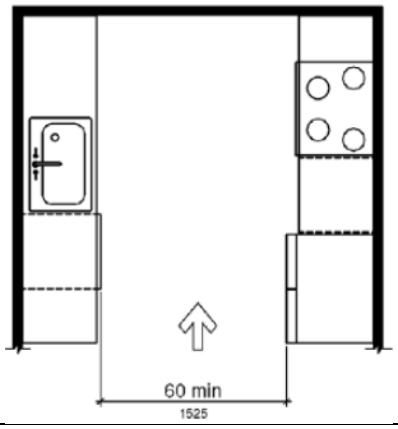
<table>
<tr><th colspan="6">Space Planning Dimension Check List</th></tr>
<tr><td colspan="6">General Dimension (for whole house use)</td></tr>
<tr><td colspan="2">Item</td><td>Standard</td><td>Dimension</td><td>Use for</td><td>Exception</td></tr>
<tr><td colspan="2">Clear Space</td><td>ADA 305.3</td><td> 
</td><td>Forward or parallel approach to any object</td><td></td></tr>
<tr><td rowspan="2">Turning Space</td><td>Circular</td><td>ADA 304.3</td><td> 
</td><td>Anywhere you need to turn / rotate (each room has at least one place for turning)</td><td>If no device use, and future use is not in consideration can choose not to provide this space.</td></tr>
<tr><td>T-shape</td><td>ADA 304.3.2</td><td> 
</td><td>For the space can’t position the full circular turning space</td><td>If no device use, and future use is not in consideration can choose not to provide this space.</td></tr>
</table>

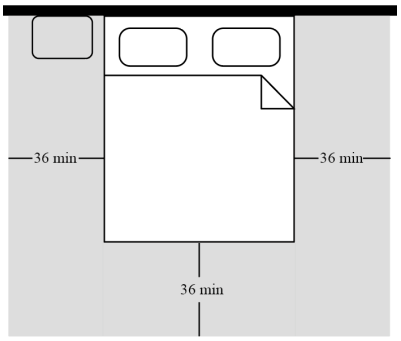
Knee Clearance & Toe Space	ADA 306.3	Knee Space: 27in min. height by 30in min. width Toe Space: 9in min. height 	Any knee space needed object	If no seated mobility devices use a nd no consideration for future use can choose not to provide this space.
Passage	ADA 403.5	36in min.	All the passage in the house	For crutches user may need bigger passage due to the swing and spread of the crutches during walking 
Entrance Space Planning				
Item	Standard	Dimension	Use for	Exception
Doorway	ADA 404.2	36in min.	All the doorway in the house	For users in limited spaces or not using any devices, the doorway size can be reduced to a 32 in min.
Doorway	ADA 404.2	Pull Side: 60in min. perpendicular to the doorway,		

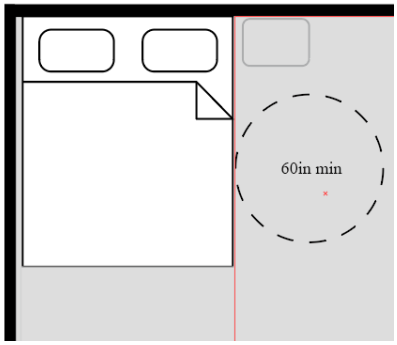
		and an additional 18in min. near the door.  Push Side: 48 in min. perpendicular to doorway. 	All the door in the house	
Bathroom Space Planning				
Item	Standard	Dimension	Use for	Exception
Toilet Position	ADA 604.2	Shall be located with walls on the rear and one side, with the centerline of the toilet being 16in min. to 18in max. from the side wall.  	At least one toilet needs to comply with this standard	
Toilet Clearance	ADA 604.3	 	At least one toilet needs to comply with this standard	If no seated mobility devices use and no consideration for future use can only provide clear

				approach space.
Lavatory	ADA 606	Shall have a clear space for a forward approach (30in min by 48in min) Knee and toe clearance shall be provided (27in min height by 30in min width)	At least one toilet needs to comply with this standard	If no seated mobility devices use and no consideration for future use can only provide clear approach space.
Regular Bathtub Clearance	ADA 607.2	Shall have length of bathtub by 30in min. width clearance in front of bathtub. 	At least one bathroom needs to comply with this standard	Allow to place a compliant lavatory in the front
Built in Seat Bathtub Clearance	ADA 607.2	The clearance shall extend 12in min. at the end of bathtub. 	Only for build in seat bathtub	Allow to place a compliant lavatory in the front

Transfer Shower	ADA 608.2	Standard transfer shower shall have 36in by 36in a clear inside room. 		
Transfer Shower Clearance	ADA 608.2		Only for transfer shower	
Roll-in Shower	ADA 608.2	The standard roll-in shower shall have a 60in min. width and 30in min, depth clear inside room. 		
Roll-in Shower Clearence	ADA 608.2	Shall have 60in min. length by 30in min. depth front the open face. 	Only for Roll-in shower	Allow to place a compliant lavatory in the front

Kitchen Space Planning				
Item	Standard	Dimension	Use for	Exception
Pass Through Kitchen	ADA 804.2	Shall be 40in min. clearance. 	For Pass through kitchen clearance	
U-shape Kitchen	ADA 804.2	Shall be 60in min. clearance.  	For U-shape kitchen clearance	If a kitchen doesn't provide a cooktop, the clearance can be reduced to 40in min.

Sink	ADA 804.4	Shall have a clear space for a forward approach (30in min by 48in min) Knee and toe clearance shall be provided (27in min height by 30in min width)	For all sink in the kitchen	If no seated mobility devices use and no consideration for future use can only provide clear approach space.
Cooktop	ADA 804.5	Shall provide a clear floor space for a parallel or forward approach (30in min. by 48in min.) If clear space is positioned for forward approach, knee and toe clearance shall be provided.	For all cooktop	If no seated mobility devices use and no consideration for future use can only provide clear approach space.
Appliances		All the appliances shall provide a clear floor space for a parallel or forward approach (30in min. by 48in min.)		
Bedroom (There are no standards for bedroom space requirement, the following are derived from author's analysis and summary.)				
Item	Standard	Dimension	Use for	Exception
Bed Clearence		36in min. clear space around the bed  	Maneuvering space around bed	Allow bedside table placed beside the head of the bed.

Turning Space			Have at least one turning space in bedroom	
Closet		The doorway should be 36in min. Should provide clear space for forward approach (30in min. by 48in min.)	For closet entry and approach	For users in limited spaces or not using any devices, the doorway size can be reduced to a 32 in min.
Clear space		Should provide a clear floor space for a parallel or forward approach (30in min. by 48in min.)	For all furniture/object approach	
Others (For any other rooms which not specifically defined, such as living room, dining room, washing room…)				
Clear space		Should provide a clear floor space for a parallel or forward approach (30in min. by 48in min.)	For all furniture/ appliances /objects approach in the whole house.	
Knee Clearance		Knee Space: 27in min. height by 30in min. width	For forward approach of working or operated object.	If no seated mobility devices use and no consideration for future use can only provide clear approach space.

Passage		36in minimum width	The clear passage between objects	Crutches user may need wider to 48in minimum

3.4 Home Fixture & Furniture Design and Choose

It is known that the doorway size must be at least 36 inches and must have sufficient maneuvering space and clear space. It's important to note that doorway size does not equate to door size; the actual size of the door can be purchased or customized based on the required dimensions of the doorway. Additionally, the placement and style of door handles are very important.

While ADA and ANSI do not have specific height requirements for door handles, the International Building Code states (2018): "Door handles, pulls, latches, locks, and other operating devices shall be installed 34 inches (864 mm) minimum and 48 inches (1219 mm) maximum above the finished floor.".

As mentioned in Chapter 2, users of mobility devices may find it difficult to operate doors. Adding an auxiliary handle inside the door is one solution (Mace, 1991); thus, installing a small loop-type handle near the hinge can help solve this problem (Figure 56). The auxiliary handle should be installed no more than 6 inches from the hinge edge, and the height should be the same as the main handle (Mace, 1991).

After determining the handle position, choosing the shape of the handle is also crucial. ADA standards specify that door handles must allow one-hand operation, not require gripping, twisting, or pinching, and operate with no more than five pounds of force. To determine if a handle or button is accessible, try operating it with a clenched hand; if it functions properly, it is considered an excellent choice for a handle or button (Mace, 1991). As Figure 57, a lever handle can be easily operated by a clenched hand. If it is undesirable to dismantle or replace the door, round knobs can be adapted by adding a lever handle over the existing knob for easier use, and this addition can be removed at any time if no longer needed (see Figure 58).

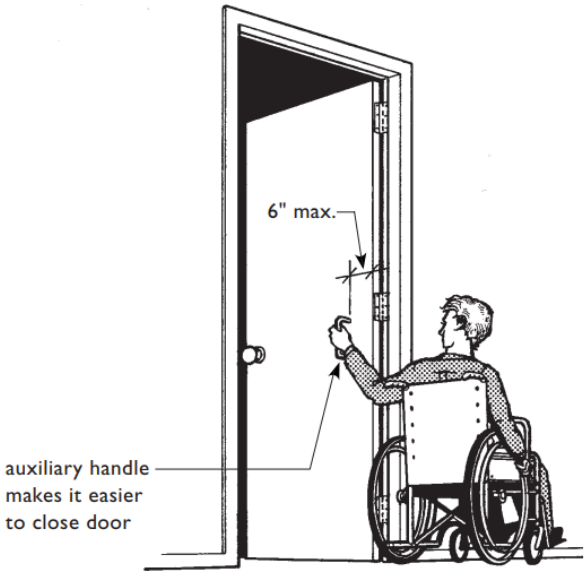


Figure 56 Auxiliary Handle (Mace, 1991)

Figure 57 Lever Handle

Figure 58 Handle Cover (*Https://Www.Thewrightstuff.Com/Leveron-Doorknob-Handles-2pack.Html*, n.d.)

3.4.2 Bathroom

As Chapter 2 mentions, bathrooms are high-risk areas for accidents, with many incidents caused by slips and falls. Thus, keeping the floor dry and free from water accumulation is crucial. To reduce the risk of falling, it is advisable to divide the bathroom into dry and wet areas. Using a shower curtain to separate these areas is a simple and effective method, and enhancing the drainage in the bathroom can further prevent water accumulation and subsequently reduce the risk of falls due to wet floors (Lawlor & Thomas, 2008)

In section 2.7.3, three common bathing fixtures for people with mobility impairments are introduced: tubs with built-in transfer seats, transfer showers, and roll-in showers. Users can choose based on personal preference. It is particularly important for wheelchair users to ensure that when selecting a tub with a built-in transfer seat, the seat should ideally be the same height as the wheelchair to facilitate easier transfers. For those opting for a roll-in shower, designers

should ensure there is adequate maneuvering space as required by ADA standards. Additionally, the entry to a transfer shower and all doorways with doors should be no less than 36 inches wide (ADA, 2010).

The height of the toilet directly affects the user experience. For wheelchair users, the optimal toilet height is the same as their wheelchair height, as this makes transfers between the wheelchair and toilet easier. When using the toilet, users' feet should reach the floor, and squatting or standing should not put excessive pressure on the lower limbs (too low a toilet height increases strain on the legs and lower back). For other users (not using seated mobility devices), the best toilet height allows the user to sit with knees at a 90° angle and feet flat on the floor (Mace, 1991). Therefore, the choice of toilet height should reference the popliteal height data, selecting a toilet height equal to or slightly lower than the popliteal height as per user preference.

If users need to install handles to assist in squatting, standing, or transferring, ANSI standards (2017) can be referred to. As shown in the diagram, the side wall grab bar shall be a minimum of 42 inches long and located a maximum of 12 inches from the rear wall. The rear wall grab bar shall be a minimum of 36 inches long and located a maximum of 6 inches from the side wall, with both at heights ranging from 33 inches minimum to 36 inches maximum.

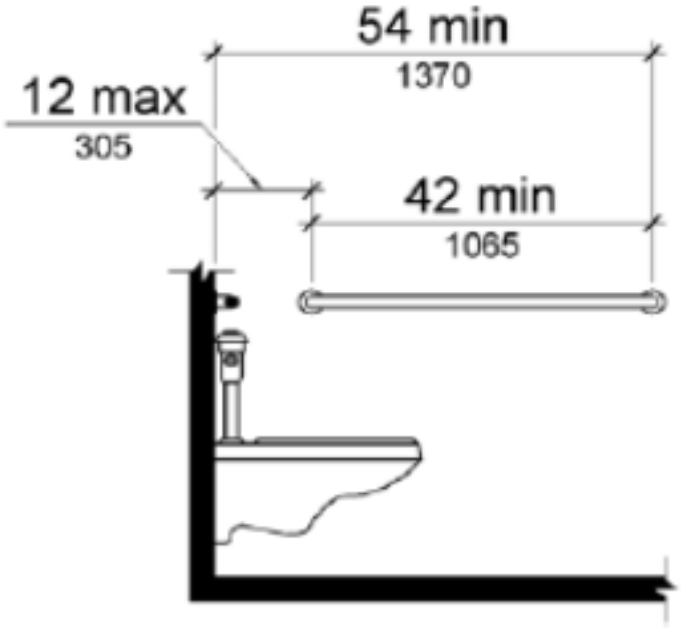


Figure 59 Rear Wall Grab Bar (ADA, 2010)

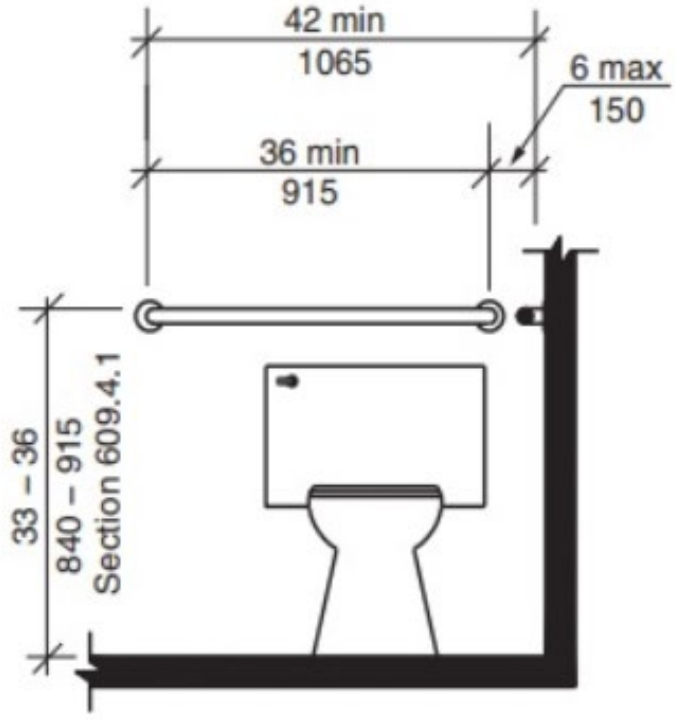


Figure 60 Side Wall Grab Bar (ADA, 2010)

3.4.3 Kitchen

Standard kitchen counters are typically 36 inches high, which suits most standing users (Mace, 1991). However, the ADA (2010) specifies that kitchen workspaces should be no more than 34 inches high from the floor, taking into account the accessible range for wheelchair users. The optimal counter height is about 3 inches below elbow height, which is also applicable to other kitchen working surfaces like sinks and cooktops (Panero & Zelnik, 1979). For families with varying height requirements (between standing and seated users) or those considering future potential needs for wheelchair accessibility, adjustable height features may be a viable solution. This feature allows for the adjustment of the height of counters, cooktops, and sinks via a switch to meet different users' needs (Figure 61).

A user's reach range directly affects multiple dimensions such as countertop depth, shelf height, and wall cabinet placement. The countertop depth should not exceed the user's maximum hand reach width (Mace, 1991) to ensure maximum usability, and the shelf height should not be higher than the max hand reach height. Due to the limited reach range of some users, drawers are more suitable for use by people with mobility impairments than cabinets. Full-extension drawers (Figure 62) are a good choice, making it easier for users to access items deep inside (1991). When the drawer is in a higher position (above eye level), it may cause difficulty for users to see inside items; in such cases, full-extension drawers with low sides is a perfect choice, as they allow full visibility and easy access.

For wheelchair users or shorter individuals, the upper sections of wall cabinets may be out of reach. Pull-down cabinets are an excellent solution to utilize upper space while ensuring accessibility (Figure 63). Chapter 2.7.4 mentions the risk of burns from rear-control elements, thus recommending front-control cooktops. A countertop cooktop is ideal for wheelchair users

because it can be installed at a lower height and provides ample knee room underneath (Figure 64).

The placement of home appliances should ensure there is sufficient space for approach. Common ovens are usually installed at a lower position, which can pose difficulties for some users. Without relocating the oven, providing knee space beside a range can help wheelchair users get closer to the oven. Additionally, a wall oven can be a suitable option for most users, as it avoids the need to bend and lift from a lower position. For wheelchair users, it is advantageous to have knee space at least on one side to facilitate operation.

Figure 61 Adjustable Counter (*Height Adjustable Kitchen*, n.d.)

Figure 62 Full Extension Drawer (Full Extension, Deep Top Drawers, n.d.)

Figure 63 Pull down shelf (*Pull Down Cabinet*, n.d.)

Figure 64 The Countertop Cooktop (*Adapted Kitchen Design for Wheelchair Users*, n.d.)

3.4.4 Bedroom

- Bed Height

For wheelchair users, transferring between a bed and a wheelchair can be a significant challenge. To facilitate easier and more convenient transfers, it is best that bed height is the same as the seat height of wheelchair and have enough space beside the bed to accommodate the wheelchair operation (Mace, 1991). For users with other mobility issues, the combined height of the bed and mattress should be equal to or slightly lower than the popliteal height.

Moreover, adding a fixed handle at the edge of the bed, with the height of handle determined by the individual body size, ensures the design meets the need of users with different movement abilities (Yang et al., 2019).

- Table/Desk

While most tables and desks are usable by the majority of people, the ideal height of a table should be the seat height plus seven inches to accommodate the knees comfortably (Dreyfuss, 1967). For wheelchair users, it's important to ensure there is sufficient space under the table for the knees.

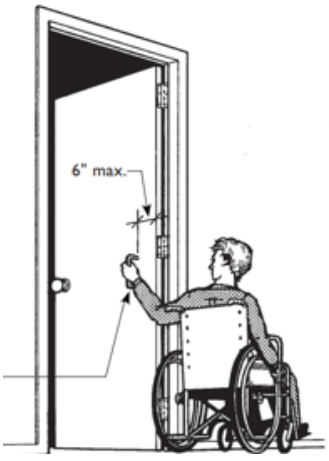
- Closet

Firstly, the doorway of a closet should also have a minimum width of 32 inches. If the closet is wider, the doorway should be widened accordingly to prevent areas that are unreachable for the user. The layout of the closet should consider the user's maximum reach height to avoid placing shelves or hanging rods too high, which could make them unusable or difficult to use for individuals with limited reach.

3.4.5 Home Fixture & Furniture Guideline for Both Choosing & Designing

The author developed a guideline to assist designers in choosing and designing home fixtures and furniture. This guideline provides dimensional recommendations to different types of users, and these recommendations are distinctly marked with different colors to facilitate easy reference for designers seeking specific measurements.

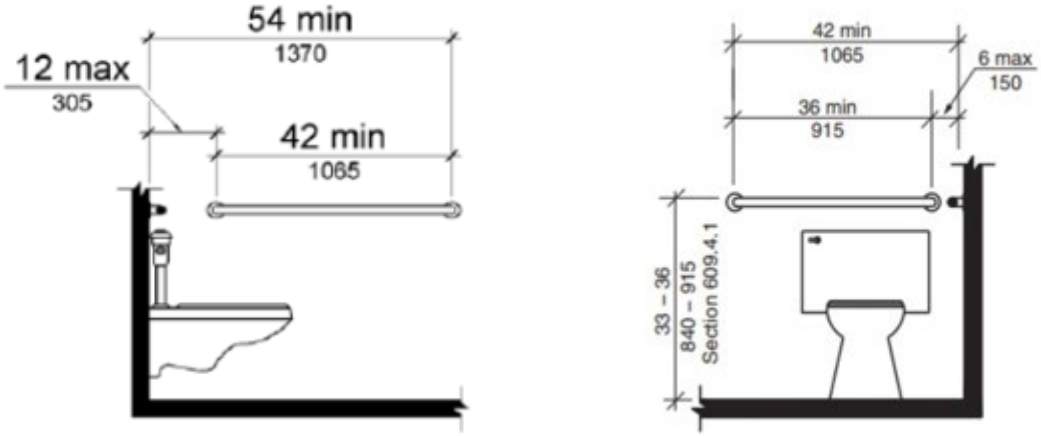
Table 9 Home Fixture & Furniture Guideline for Both Choosing & Designing

<table>
<tr><th colspan="4">Home Fixture & Furniture Guideline for Both Choosing & Designing</th></tr>
<tr><td colspan="4">Door</td></tr>
<tr><td></td><td>Standard/Principle</td><td colspan="2">User Required</td></tr>
<tr><td rowspan="3">Handle height</td><td rowspan="3">34in min. to 48in max.</td><td>Wheelchair User</td><td>Other User</td></tr>
<tr><td>Below P5: 34in to 40in max.</td><td rowspan="2">34in min. to 48in max.</td></tr>
<tr><td>P5~P95: 40in to 48in max.</td></tr>
<tr><td>Handle Choose</td><td>Allow on-hand operation, not require hand gripping, twisting, or pinching, and no more than 5 pounds to operate.</td><td colspan="2">The lever handle or lever cover are recommended.
   </td></tr>
<tr><td>Auxiliary Handle (Optional)</td><td>An auxiliary handle should be installed at a position 6 inches maximum from the hinge edge.
  </td><td colspan="2">The center height of an auxiliary handle should be consistent with the center height of a normal handle.</td></tr>
</table>

<table>
<tr><th colspan="5">Bathroom</th></tr>
<tr><td></td><td>Standard/Principle</td><td colspan="3">User - required</td></tr>
<tr><td rowspan="5">Toilet Height</td><td rowspan="5">Stander toilet height: 14in to 17in

Extra Tall toilet: 17in up

ADA Stander for wheelchair toilet height: 19in max.

Suitable toilet height should be similar or equal to the people popliteal height or wheelchair users' seat height.</td><td rowspan="2">Wheelchair User</td><td colspan="2">Other User</td></tr>
<tr><td>Male</td><td>Female</td></tr>
<tr><td>Below P5: 14in to 15in</td><td>Below 65y
P1~P50:
16.5in to 18in</td><td>Below 65y
P1~P50: 15in to 16.5in</td></tr>
<tr><td>P5~P50: 15in to 18in</td><td>Below 65y
P50~P99:
18in to 19.5in</td><td>Below 65y
P50~P99:
16.5in to 17.5in</td></tr>
<tr><td rowspan="2">P50~P95: 18in to 19in</td><td>Above 65y
P1~P50:
15.5in to 17.5in</td><td>Above 65y
P1~P50: 14in to 16in</td></tr>
<tr><td>Above 65y
P50~P99:
17.5in to 19in</td><td>Above 65y
P50~P99:
16in to 18.5in</td></tr>
<tr><td>Grab Bar for Toilet</td><td colspan="4">The side wall grab bar: 42in min. long located 12in max. from the rear wall.
The rear wall grab bar: 36in min. long located 6in max. from the side wall.
Both heights should be between 33in min. to 36 inches max.
 
</td></tr>
<tr><td rowspan="2">Lavatory</td><td rowspan="2">ADA: 34in max. height. for wheelchair users.</td><td rowspan="2">Wheelchair User</td><td colspan="2">Other User</td></tr>
<tr><td>Male</td><td>Female</td></tr>
</table>

<table>
<tr><td rowspan="4">Height</td><td rowspan="4">Suitable lavatory height should be 3in less than elbow height.</td><td rowspan="4">34in max. Height

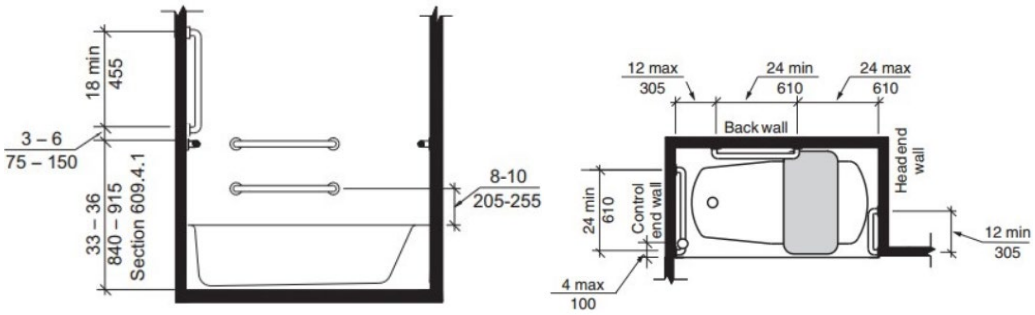
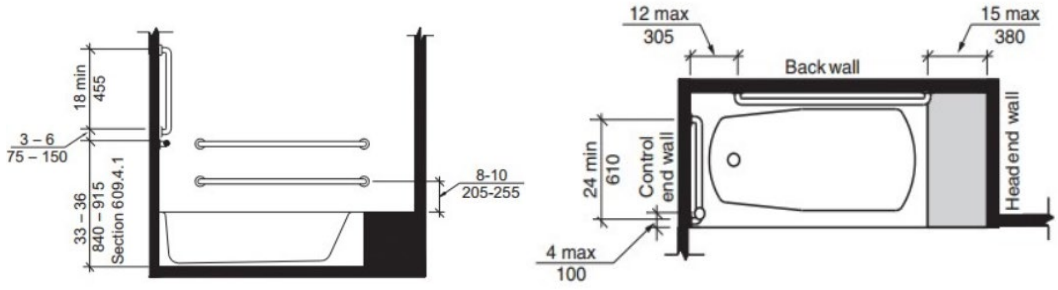
Addition: Shall provide knee space (27in min. height)</td><td>Below 65y P1~P50: 35in to 39in</td><td>Below 65y P1~P50: 32in to 36in</td></tr>
<tr><td>Below 65y P50~P99: 39in to 43in</td><td>Below 65y P50~P99: 36in to 40in</td></tr>
<tr><td>Above 65y P1~P50: 33in to 37in</td><td>Above 65y P1~P50: 31in to 35</td></tr>
<tr><td>Above 65y P50~P99: 37in to 41in</td><td>Above 65y P50~P99: 35in to 38in</td></tr>
<tr><td rowspan="4">Depth</td><td rowspan="4">ANSI: 25in max. depth for wheelchair user.

Suitable lavatory depth should not exceed the depth of arm grip reach.</td><td rowspan="4">34in max. Depth</td><td>Below 65y P1~P50: 26in to 29in</td><td>Below 65y P1~P50: 24in to 26in</td></tr>
<tr><td>Below 65y P50~P99: 29in to 33in</td><td>Below 65y P50~P99: 26in to 30in</td></tr>
<tr><td>Above 65y P1~P50: 21in to 26in</td><td>Above 65y P1~P50: 21in to 25in</td></tr>
<tr><td>Above 65y P50~P99: 26in to 28in</td><td>Above 65y P50~P99: 25in to 28in</td></tr>
<tr><td>Faucet Choose</td><td>Allow on-hand operation, not require hand gripping, twisting, or pinching, and no more than 5 pounds to operate</td><td colspan="3">Should choose asymmetrical shape handle without grasping and twisting.

  </td></tr>
</table>

<table>
<tr>
<td>Bathtub</td>
<td>Have a seat for rest during shower.

Have grab bar for support.</td>
<td>If choosing a standard bathtub, better to provide a removable in tub seat, or should choose the built in seat bathtub.

 
  </td>
</tr>
<tr>
<td rowspan="2">Grab Bar for Bathtub</td>
<td colspan="2">Grab bars for bathtubs with removable seats:
 
</td>
</tr>
<tr>
<td colspan="2">Grab bars for bathtubs with built in seats:
 
</td>
</tr>
</table>

<table>
<tr><td>Shower Compartments</td><td>Enough space allows wheelchair users to transfer or enter.

Have a seat for rest during shower.

Have grab bar for support.</td><td colspan="3">Roll-in shower and Transfer are both good choices.

 
Roll-in Shower

 
Transfer shower</td></tr>
<tr><td colspan="5">Kitchen</td></tr>
<tr><td></td><td>Standard/Principle</td><td colspan="3">User Required</td></tr>
<tr><td rowspan="2">Kitch Counter</td><td rowspan="5">

ADA: 34in max. height. for wheelchair users.

Suitable counter height should be 3in less than elbow height.</td><td rowspan="2">Wheelchair User</td><td colspan="2">Other User</td></tr>
<tr><td>Male</td><td>Female</td></tr>
<tr><td rowspan="4">Height</td><td rowspan="4">34in max. Height

Addition: At least for one knee space under counter (27in min. height)</td><td>Below 65y P1~P50: 35in to 39in</td><td>Below 65y P1~P50: 32in to 36in</td></tr>
<tr><td>Below 65y P50~P99: 39in to 43in</td><td>Below 65y P50~P99: 36in to 40in</td></tr>
<tr><td>Above 65y P1~P50: 33in to 37in</td><td>Above 65y P1~P50: 31in to 35in</td></tr>
<tr><td>Above 65y P50~P99: 37in to 41in</td><td>Above 65y P50~P99: 35in to 38in</td></tr>
<tr><td rowspan="3">Depth</td><td rowspan="3">ANSI: 25in max. depth for wheelchair user.

Suitable counter depth should not exceed the depth of arm grip reach.</td><td rowspan="3">34in max. depth</td><td>Below 65y P1~P50: 26in to 29in</td><td>Below 65y P1~P50: 24in to 26in</td></tr>
<tr><td>Below 65y P50~P99: 29in to 33in</td><td>Below 65y P50~P99: 26in to 30in</td></tr>
<tr><td>Above 65y P1~P50: 21in to 26in</td><td>Above 65y P1~P50: 21in to 25in</td></tr>
</table>

<table>
<tr><td></td><td></td><td></td><td>Above 65y
P50~P99:
26in to 28in</td><td>Above 65y
P50~P99:
25in to 28in</td></tr>
<tr><td>Cooktop
Height</td><td colspan="4">Same requirement with counter height</td></tr>
<tr><td>Depth</td><td colspan="4">Same requirement with counter depth</td></tr>
<tr><td>Control
Button</td><td colspan="4">All rear-control cooktops should be avoided.
 
Should choose front-control cooktops.
  </td></tr>
<tr><td>Under
Conter</td><td>Ensure Accessibility
Reduce Bending/
Scooping
Avoid Squatting</td><td colspan="3">Drawers are more suitable than cabinets, full-extension drawers are good choice.
  </td></tr>
<tr><td rowspan="3">Upper
Cabinet</td><td rowspan="3">Accessible Upper Cabinet Placed Height: 15in to 18in from countertop.

Standard Upper Cabinet placed Height: 18in to 22in from countertop.</td><td rowspan="3">Wheelchair User</td><td colspan="2">Other User</td></tr>
<tr><td>Male</td><td>Female</td></tr>
<tr><td>Upper cabinets are all hard for wheelchair users to access. Consider pull-down cabinets or shelves for easier reach.</td><td>Below 65y
P1~P50: 74in to 82in grip reach height</td><td>Below 65y
P1~P50: 68in to 76in grip reach height</td></tr>
<tr><td></td><td>Below 65y
P50~P99: 82in to 91in grip reach height</td><td>Below 65y
P50~P99:
76in to 84in grip reach height</td></tr>
</table>

<table>
<tr><td></td><td>The height of upper cabinets is all personal preference, but it should not exceed grip reach height.</td><td>  </td><td>Above 65y P1~P50: 66in to 73in grip reach height</td><td>Above 65y P1~P50: 58in to 69in grip reach height</td></tr>
<tr><td></td><td></td><td></td><td>Above 65y P50~P99: 73in to 78in grip reach height</td><td>Above 65y P50~P99: 69in to 75in grip reach height</td></tr>
<tr><td></td><td></td><td></td><td colspan="2">For shorter users, pull-down cabinets or shelves are also recommended for easier access.</td></tr>
<tr><td>Range Oven</td><td>Need sufficient approach space, either forward or parallel</td><td>For wheelchair users, recommended to leave knee space beside the oven.
  </td><td colspan="2">Range ovens are usually installed in a lower position which is difficult for most mobility issues standing people to use.
  </td></tr>
</table>

<table>
<tr><td>Wall Oven</td><td></td><td colspan="3">Wall oven can be a better choice for most people without bending or lifting from lower heights. (Wall ovens can be placed at any height, but for wheelchair user, the oven button shouldn’t higher than 48in.)
  </td></tr>
<tr><td colspan="6">Bedroom</td></tr>
<tr><td rowspan="5">Bed Height (including mattress height)</td><td rowspan="5">Suitable bed height should be similar or equal to the people popliteal height or wheelchair users’ seat height.</td><td rowspan="2">Wheelchair User</td><td colspan="2">Other User</td></tr>
<tr><td>Male</td><td>Female</td></tr>
<tr><td rowspan="2">P5~P50: 15in to 18in</td><td>Below 65y P1~P50: 16.5in to 18in</td><td>Below 65y P1~P50: 15in to 16.5in</td></tr>
<tr><td>Below 65y P50~P99: 18in to 19.5in</td><td>Below 65y P50~P99: 16.5in to 17.5in</td></tr>
<tr><td>P50~P95: 18in to 22in</td><td>Above 65y P1~P50: 15.5in to 17.5in</td><td>Above 65y P1~P50: 14in to 16in</td></tr>
<tr><td>Closet
Opening</td><td>ADA: 36in min. width of Doorway</td><td colspan="3">36in min. doorway for closet opening</td></tr>
<tr><td rowspan="2">Storage Height</td><td rowspan="2"></td><td rowspan="2">Wheelchair User</td><td colspan="2">Other User</td></tr>
<tr><td>Male</td><td>Female</td></tr>
</table>

	ADA: 48in max. Height for wheelchair user. For others, to ensure the fully accessible, storage height should not exceed vertical grip height.	48in max. of Storage Height	Below 65y P1~P50: 74in to 82in grip reach height	Below 65y P1~P50: 68in to 76in grip reach height
			Below 65y P50~P99: 82in to 91in grip reach height	Below 65y P50~P99: 76in to 84in grip reach height
			Above 65y P1~P50: 66in to 73in grip reach height	Above 65y P1~P50: 58in to 69in grip reach height
			Above 65y P50~P99: 73in to 78in grip reach height	Above 65y P50~P99: 69in to 75in grip reach height
Other Common Furniture				
Seat Furniture	Suitable seat height should be similar or equal to the people popliteal height or wheelchair users' seat height.	Wheelchair User	Other User	
			Male	Female
Height		P5~P50: 15in to 18in	Below 65y P1~P50: 16.5in to 18in	Below 65y P1~P50: 15in to 16.5in
			Below 65y P50~P99: 18in to 19.5in	Below 65y P50~P99: 16.5in to 17.5in
		P50~P95: 18in to 22in	Above 65y P1~P50: 15.5in to 17.5in	Above 65y P1~P50: 14in to 16in
			Above 65y P50~P99: 17.5in to 19in	Above 65y P50~P99: 16in to 18.5in
Width	Suitable seat width must not be less than the hip breadth.	P5~P50: 16in min. width	Below 65y P1~P50: 15in min. width	Below 65y P1~P50: 15in min. width

<table>
<tr><td rowspan="3"></td><td rowspan="3"></td><td></td><td>Below 65y P50~P99: 17in min. width</td><td>Below 65y P50~P99: 18.5in min. width</td></tr>
<tr><td rowspan="2">P50~P95: 18in min. width</td><td>Above 65y P1~P50: 15.5in min. width</td><td>Above 65y P1~P50: 16in min. width</td></tr>
<tr><td>Above 65y P50~P99: 18in min. width</td><td>Above 65y P50~P99: 19in min. width</td></tr>
<tr><td rowspan="5">Depth</td><td rowspan="5">Suitable seat depth should be 2in greater than the buttock-popliteal length.</td><td>Below P5: 19in max.</td><td>Below 65y P1~P50: 19.5in to 22in</td><td>Below 65y P1~P50: 18.5in to 21.5in</td></tr>
<tr><td>P5~P50: 19in. to 21in.</td><td>Below 65y P50~P99: 22in to 24in</td><td>Below 65y P50~P99: 21.5in to 23in</td></tr>
<tr><td rowspan="3">P50~P95: 21in to 23in.</td><td>Above 65y P1~P50: 19in to 21in</td><td>Above 65y P1~P50: 18.5in to 21in</td></tr>
<tr><td>Above 65y P50~P99: 21in to 23in</td><td>Above 65y P50~P99: 21in to 23in</td></tr>
<tr><td>Table/ Desk</td><td rowspan="3">ADA: 34in max. height. for wheelchair users and 27in min height for knee space.

For others: The height of the table should be at least 7 inches higher than the seat height to</td><td rowspan="2">Wheelchair User</td><td colspan="2">Other User</td></tr>
<tr><td>Height</td><td>Male</td><td>Female</td></tr>
<tr><td>27in min to 34in max</td><td>Below 65y P1~P50: 23.5in to 25in min.</td><td>Below 65y P1~P50: 22in to 23.5in min.</td></tr>
<tr><td></td><td></td><td>Below 65y P50~P99: 25in to 26.5in min.</td><td>Below 65y P50~P99: 23.5in to 20.5 min.</td></tr>
</table>

<table>
<tr><td rowspan="2"></td><td rowspan="2">accommodate knee space.</td><td rowspan="2" colspan="2"></td><td>Above 65y P1~P50: 22.5in to 24.5in min.</td><td>Above 65y P1~P50: 21.5in to 23.5in min</td></tr>
<tr><td>Above 65y P50~P99: 24.5in to 26in min.</td><td>Above 65y P50~P99: 23.5in to 25.5 min.</td></tr>
<tr><td>Depth</td><td>ADA: 25in max for worktop depth.</td><td colspan="2">25in max depth</td><td colspan="2">The depth of the table can be determined based on user preference and specific use but cannot be less than 18 inches.</td></tr>
<tr><td rowspan="6">Storage Height</td><td rowspan="6">ADA: For forward approach, 48in max. height of high reach; 15in min. of low reach.

For side approach, 54in max. of high reach; 9in min. of low reach.

For others: high reach cannot exceed vertical grip reach, low reach cannot be less than 15in.</td><td colspan="2" rowspan="2">Wheelchair User (Approach Range)</td><td colspan="2">Other User (High Reach Range)</td></tr>
<tr><td>Male</td><td>Female</td></tr>
<tr><td>Forward:

Below P5: 15in min. to 40in max.</td><td>Side:

Below P5: 9in min. to 51in max.</td><td>Below 65y P1~P50: 74in to 82in grip reach height</td><td>Below 65y P1~P50: 68in to 76in grip reach height</td></tr>
<tr><td rowspan="2"></td><td rowspan="2"></td><td>Below 65y P50~P99: 82in to 91in grip reach height</td><td>Below 65y P50~P99: 76in to 84in grip reach height</td></tr>
<tr><td rowspan="2">P5~P95: 15in min. to 48in max.</td><td rowspan="2">P5~P95: 9in min. to 54in max.</td><td>Above 65y P1~P50: 66in to 73in grip reach height</td><td>Above 65y P1~P50: 58in to 69in grip reach height</td></tr>
<tr><td>Above 65y P50~P99: 73in to 78in grip reach height</td><td>Above 65y P50~P99: 69in to 75in grip reach height</td></tr>
</table>

3.5 Application of Modular Furniture Design

The modular design concept helps people with mobility issues to combine furniture that meets their needs and allows individual modules and parts to be changed to adapt to new conditions as their physical state changes.

3.5.1 Module Type

Modules are mainly divided into two types, modules with independent function and modules without independent function. For modules with independent functions, each module has its own function and can be used independently or combined with other modules to build a new product. There are usually no independent function module; instead, they typically appear as various elements without any function and require assembly with other modules to create functional furniture (Zhang, 2023). Depending on the type of furniture, the designer can decide what type of modules to use. Usually, modules with independent functions are faced with frequent changes and relocations, while modules without independent functions usually remain in one form for a long period of time. For example, modular sofas and tables often use modules with independent functions that can be moved and changed at any time according to the user's needs (Figure 65). Modular closets, counters, etc. often use modules without independent functions, which cannot be easily changed once they are assembled according to the user's needs (Figure 66).

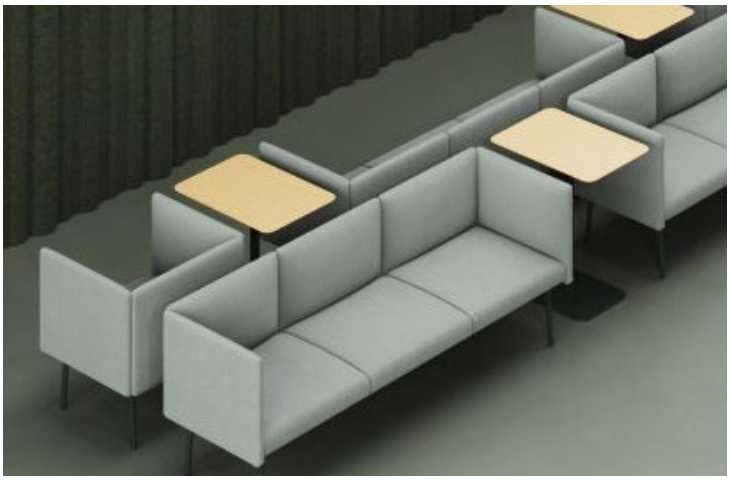


Figure 65 Modular Sofa (*Mino Sofa Series by De Vorm*, 2022)

Figure 66 Modular Closet (*Complete Compact Closet Kit*, n.d.)

3.5.2 Connect Way

Connections are very important for modular furniture, as they ensure stability and can be disassembled and reassembled at the same time. Common modular connection methods are

direct connect, built-in connection, and external connect (Zhang, 2023). However, no matter which type of connection is used, it is necessary to have a uniform interface size and standardized connectors to facilitate assembly, disassembly, and replacement (Mikkola, 2000). For modular furniture that requires frequent changes, the design of the joints needs to be easy to put together and dismantle, such as clips, magnets, or direct connections. If the modular furniture is to be maintained in one form for a long period of time and the joints need to be very stable, screws or gluing can be considered.

3.5.3 Module Design

Each module should have multiple uses, be reusable, and allow for combinations or assemblies with other modules (Du, 2020). However, there will be exceptions, sometimes according to the user's requirements or space limitations, that disallow the use of the existing module. Therefore, customized parts with the same interface can be produced, which can only be used in a specific location, and are not part of the modular system. As shown in the picture below, because of the need to install a microwave oven, the size of the cabinet has to be shortened, and this size of the panel can only be used above the microwave and can't be used elsewhere.

Figure 67 Customized Parts (Jane, 2022)

Module size is also very important; for modules with independent functions, the size of each module must meet the basic dimensions of its functional requirements, so when it is used individually proper size can also ensure functionality. For modules without independent functions, the size of the combined product must meet the basic size of its functional requirements.

3.5.4 Material Choose

Modules should be made of durable materials with flat and smooth surfaces. Durable materials can increase the life of the furniture, and materials with smooth and flat surfaces can be assembled and combined more accurately (Du, 2020; Zhang, 2023). For modular furniture that requires frequent changes, it is recommended to use lighter materials that are easy to move and assemble, such as lightweight wood, plastic, and so on.

3.5.5 Modular Furniture Design Standard

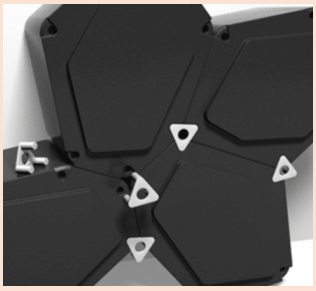
Modular furniture must meet the requirements of assimilability, relative independence of modules, functional variability and extensibility (Du, 2020; Huang, 2018).

- Assimilability: allow modules to be assembled according to users' different needs.
- Relative independence of modules: allows the disassembly and change of a single module, without affecting the whole.
- Functional variability: the diversity of functions can be realized through the combination and change between modules.
- Extensibility: By adding or changing modules, the form and function of furniture can be extended, such as wider, higher, or more functional.

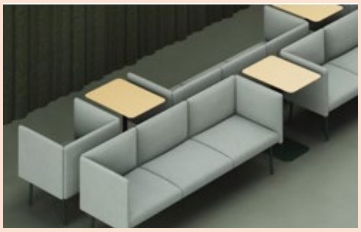
3.5.6 Modular Furniture Design Guideline

Table 10 Modular Furniture Design Guideline

Modular Furniture Design Guideline		
Step One: Decide Module Type	Modules with Independent Function (Each module has a specific **function**) Typically used for modular furniture that requires **frequent reconfiguration**. 	Modules without Independent Function (Each module **does not have a specific function**, but **have a specific position or purpose**) Typically used for modular furniture that maintains the **one configuration over a long period** and does not need frequent changes. 
Step Two: Divide Function	Determine the basic and additional functions **based on the type of furniture**. **Basic functions**: Essential functions that the type of furniture must have (such as, a chair must have a seating area, a table must have a working surface etc.) **Additional functions**: All functions beyond the basic requirement. (Such as, armrests on chairs, chair backs, footrests, etc.)	Divide functions **based on the type of combination parts.** (Such as, a cabinet unit needs to combine side panels, bottom panels, top panels, doors, etc.)

<table>
<tr><td rowspan="2">Step Three: Determine Connection Way/Design</td><td colspan="2">There are many ways to connect modules, such as direct connection, plug-in connection, magnetic connection, and external connection. However, no matter which type of connection is used, the interfaces must be of same size, and the connectors must be uniform to ensure that the modules can be interchanged and combined with each other.</td></tr>
<tr><td>These types of modules often require frequent changes or individual use by users. Therefore, the connection method or design needs to be easy to assemble and disassemble, such as clips, magnetic or direct connections.
 
  </td><td>These types of modules are typically used in a long-term fixed arrangement and are not frequently changed or reassembled. Therefore, their connections method or design need to be sturdy, such as using screws or adhesives.
  </td></tr>
</table>

<table>
<tr><td rowspan="3">Step Four:
Design Module</td><td colspan="2">Each module is designed for multiple and repeated use and can be combined or connected with other modules.
 
Exception: If required due to space needs or user requests, specially customized components with the same interfaces can be created for use only in specific locations and are not considered part of the modular system. As shown below, due to installing a microwave, the dimensions of the cabinet panel must be shortened. This size of panel can only be used above the microwave and cannot be used in other places.
  </td></tr>
<tr><td>The size of each individual module must meet the basic dimensions required for its function, ensuring functionality even when used alone.

For example, in the modular sofa as shown below, each individual module has enough room for seating one person.
  </td><td>The dimensions of these modules should coordinate and relate with each other.
For example, as shown below, the width of the top panel matches the width of the side panels.
 
Additionally, the overall dimensions of the combined product must also meet the basic dimensions required for its functionality.</td></tr>
<tr><td>Both the individual module dimensions and the dimensions after assembly should comply to ergonomic standards for furniture.</td><td>The dimensions of the combined product should comply the ergonomic standards for furniture.</td></tr>
</table>

<table>
<tr><td rowspan="2"></td><td colspan="2">Modules need have the same or consistent interface design for easy assembly and change.</td></tr>
<tr><td colspan="2">All sharp edges should be avoided to prevent injuries.</td></tr>
<tr><td rowspan="2">Material Considerations</td><td colspan="2">Should choose durable materials with a smooth surface to ensure long-term use and accurate assembly and combination.</td></tr>
<tr><td>As these modules may need frequent change, lighter materials are recommended for easy move and combination.</td><td>As these modules often require assembly of multiple pieces to provide function and stability; the materials need to be sturdy and durable.</td></tr>
<tr><td rowspan="2">Step Five: Module Combination</td><td colspan="2">The modules are relatively independent of each other (each module can be disassembled, change or update without affecting the others)</td></tr>
<tr><td colspan="2">Allow users to modify the form or function of the modular furniture according to their needs (such as, adjusting the height, or choosing drawers or shelves for storage place).</td></tr>
</table>

Chapter 4 Design Application – Using the Kitchen as Example

In this chapter, the author will design a kitchen as an example to show how to use the design approach and tables given in Chapter 3 to design an independent living environment suitable for people with mobility issues. The purpose of this chapter is to show how to use the data and guidelines to design an independent living environment appropriate for the user and to show that incorporating modular design can improve the independence of the user.

The kitchen designed in this chapter comes from the author's grandmother's old house. The grandmother is 77 years old and does not want to live with her children, so she insists on living alone, and the current kitchen has a lot of problems that make it inconvenient to use in daily life as well as having safety hazards, so it is necessary to re-design the kitchen to give the grandmother a more suitable kitchen that is more convenient, meets her various requirements, and is safe.

4.1 Know the User

According to the design approach given in Chapter 3, the first step is to know the user's basic information and user needs. First of all, the user needs to fill out the user research form. Because this chapter takes the kitchen as an example, only the kitchen-related parts are shown.

User Research		
Name: Guo Xiying	Gender: Female	Age: 77
Do you use any mobility devices? Yes ☐ No ☑ If yes, which one do you use:		
Do you have any:	☐ Hearing Impairment ☐ Speech Impairment ☐ Visual Impairment ☐ Others:	

Entrance	With easy	With difficulty	Explanation
Main Door Pass Through	☐	☐	
Bedroom Door Pass Through	☐	☐	
Bathroom Door Pass Through	☐	☐	No door
Others	☐	☐	

Kitchen	With easy	With difficulty	Explanation
Cooktop Use	☐	☑	Too High to use
Sink Use	☐	☑	Too High to use
Counter Use	☐	☑	Too High to use
Storage Use	☐	☑	Unable to reach the upper cabinets
Appliances Use	☑	☐	
Others	☐	☐	

Other problems/obstacles/:

The refrigerator is far from the cooking area and sink, making it inconvenient to use.

Additional Requirements:

Need an oven and dishwasher in the kitchen.

Considering the possibility of using a wheelchair in the future.

Figure 68 User Research of Kitchen

From the form, it can be seen that the overall design of the kitchen does not take into account the user's body data, resulting in the overall height of the working surface being too high, and the storage space can not be fully utilized. Here are some photos of the old kitchen.

Figure 69 Old Kitchen Photos

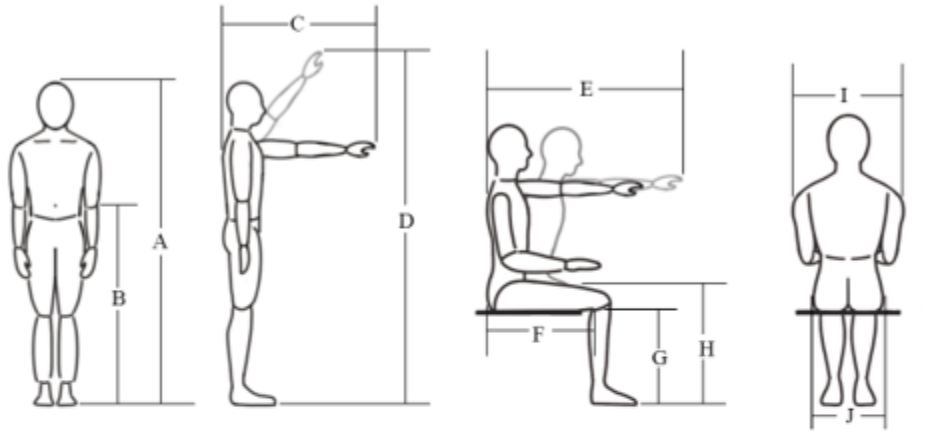
As you can see from the photos, the upper cabinet is too high, and the user only uses the space on the lower level. The upper level is not used at all, resulting in not enough storage space, the working surface is full of stuff, and the storage cabinets are too high, and the user can't reach the upper level at all. And because of the unreasonable layout of the kitchen, the refrigerator is placed in the living room, which is very inconvenient for the elderly who have difficulty with their legs and feet. Therefore, the next step is to understand the user's physical data and combine the design approach in Chapter 3 to re-plan the space appropriately.

4.2 Data Choose

According to the gender and age of the user and the consideration of using a wheelchair in the future, two sets of data are needed, one is above 65 female anthropometric data, and the other is wheelchair user anthropometric data. The age of the user is 77 years old, and the height is 61 inches, so the range of data to be considered in the form age 65 above female anthropometric data should be 1st to mean. Considering the possibility of wheelchair use, the seat stature is 48 inches tall in a 17-inch tall chair, so the range of data to be considered in the wheelchair user anthropometric data is 5th to mean.

Age 65 above Female Anthropometric Data (up to 217lb), Inch

Name: Guo Xiying Age: 77 Height: 61 inches



	Measurement	1st	Mean	99th
A	Stature	56.8	61.6	66.5
B	Elbow Height	34.3	37.9	41.5
C	Functional Grip Reach	21.7	25.6	28
D	Vertical Grip reach, Height	58	69.2	75
E	Functional Grip Reach, Extended	n/a	n/a	n/a
F	Buttock-popliteal Length	16.3	18.9	21.1
G	Popliteal Height	14.3	16.4	18.5
H	Knee Height	16.9	18.6	20.5
I	Shoulder Breadth	13.1	15.9	17.6
J	Hip Breadth (Sit)	12.9	15.7	18.6

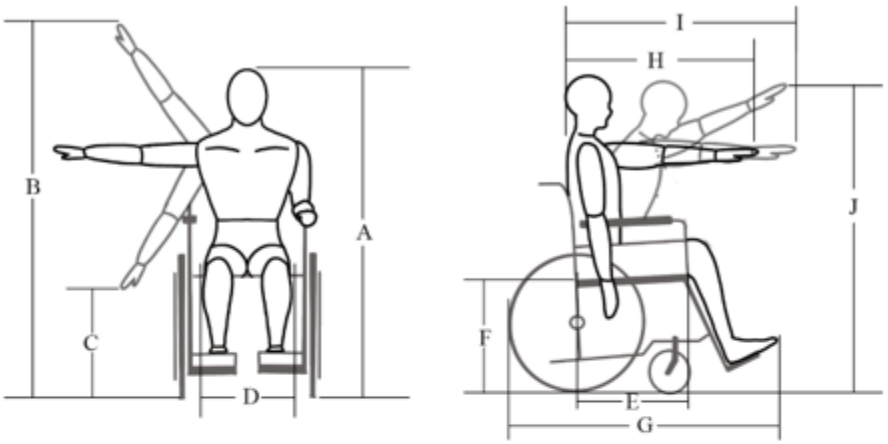
Both non-device users and standing device users can refer to the above data.

Data Source: The measure of man and woman; Anthropometric for Elderly

Figure 70 Above 65 Female Anthropometric Data Chosen

Age Above 20, Wheelchair User Anthropometric Data, Inch

Name: Guo Xiying Age: 77 Seat Height: 48 inches



	Measurement	5th	Mean	95th
A	Seated Stature	40.5	54.7	60
B	Max. Side Grip height	51	62	n/a
C	Min. Side Grip height	n/a	4.7	7.2
D	Hip Breadth	13.7	15.6	18
E	Buttock-popliteal Length	17	19	21
F	Seat Pan Height	15	18.1	22.1
G	Overall Length	36	44.3	47.8
H	Arm Reach Depth	22.5	24.8	27.1
I	Max. Side Reach Depth	30.6	33.5	36.5
J	Max. Forward Grip height	40	48.5	55.7

ADA and ANSI have clear regulations for the common dimensions needed by wheelchair users. The above dimensions are only used to narrow down the range of values or for those without specific measurements.

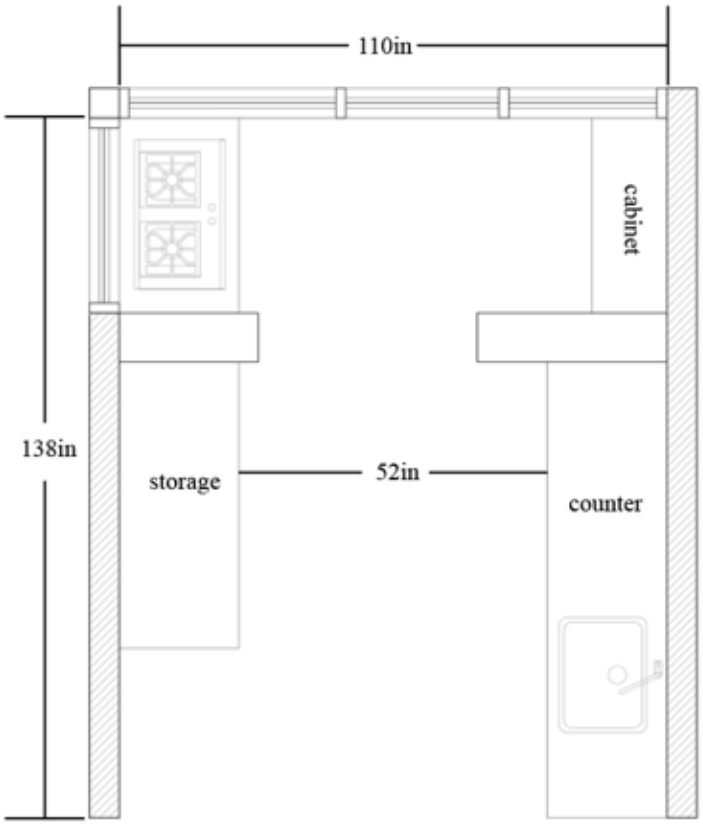
Data Source: The measure of man and woman; Structural anthropometric measurements for wheelchair mobile adults.

Figure 71 Wheelchair User Anthropometric Data Chosen

4.3 Space Planning

Before starting the redesign, it was necessary to survey and analyze the size of the kitchen and the original layout.

Space Research & Design		
Name: Guo Xiying	Date: 4/15/2024	
Location	Main Entrance ☐ Kitchen ☑	Bathroom ☐ Bedroom ☐
Length: 138 in	Width: 110 in	Height: 108 in



Current Plan

Figure 72 Kitchen Space Research

The kitchen is U-shaped. Through Chapter 3 Space Planning Dimension Check List (Figure 73), it can be found that the current passageway does not comply with the ADA regulations for a U-shaped kitchen. The cooktop, sink, and refrigerator can not form a “Kitchen Triangle”, which makes cooking less efficient. In addition, considering the possibility of using a

wheelchair in the future, there is no minimum knee space of 27 inches in height and 30 inches in width underneath the sink and counter.

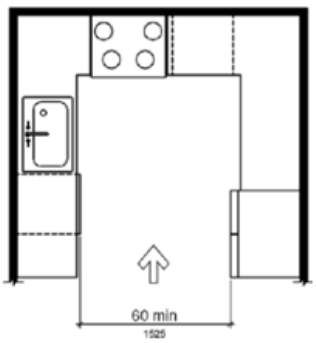
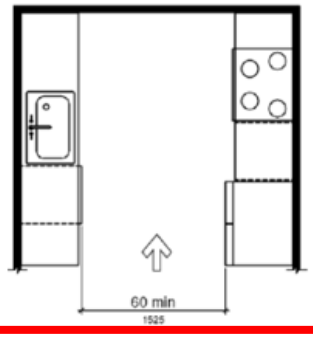
U-shape Kitchen	ADA 804.2	Shall be 60in min. clearance.   	For U-shape kitchen clearance	If a kitchen doesn't provide a cooktop, the clearance can be reduced to 40in min.
Sink	ADA 804.4	Shall have a clear space for a forward approach (30in min by 48in min) Knee and toe clearance shall be provided (27in min height by 30in min width)	For all sink in the kitchen	If no seated mobility devices use and no consideration for future use can only provide clear approach space.
Cooktop	ADA 804.5	Shall provide a clear floor space for a parallel or forward approach (30in min. by 48in min.) If clear space is positioned for forward approach, knee and toe clearance shall be provided.	For all cooktop	If no seated mobility devices use and no consideration for future use can only provide clear approach space.

Figure 73 Space Planning Dimensions Check List - Kitchen

Figure 74 shows a redesigned kitchen space plan that conforms to the dimensions provided in the Space Planning Dimension Check List. The refrigerator was placed in the kitchen, and an oven and dishwasher were added.

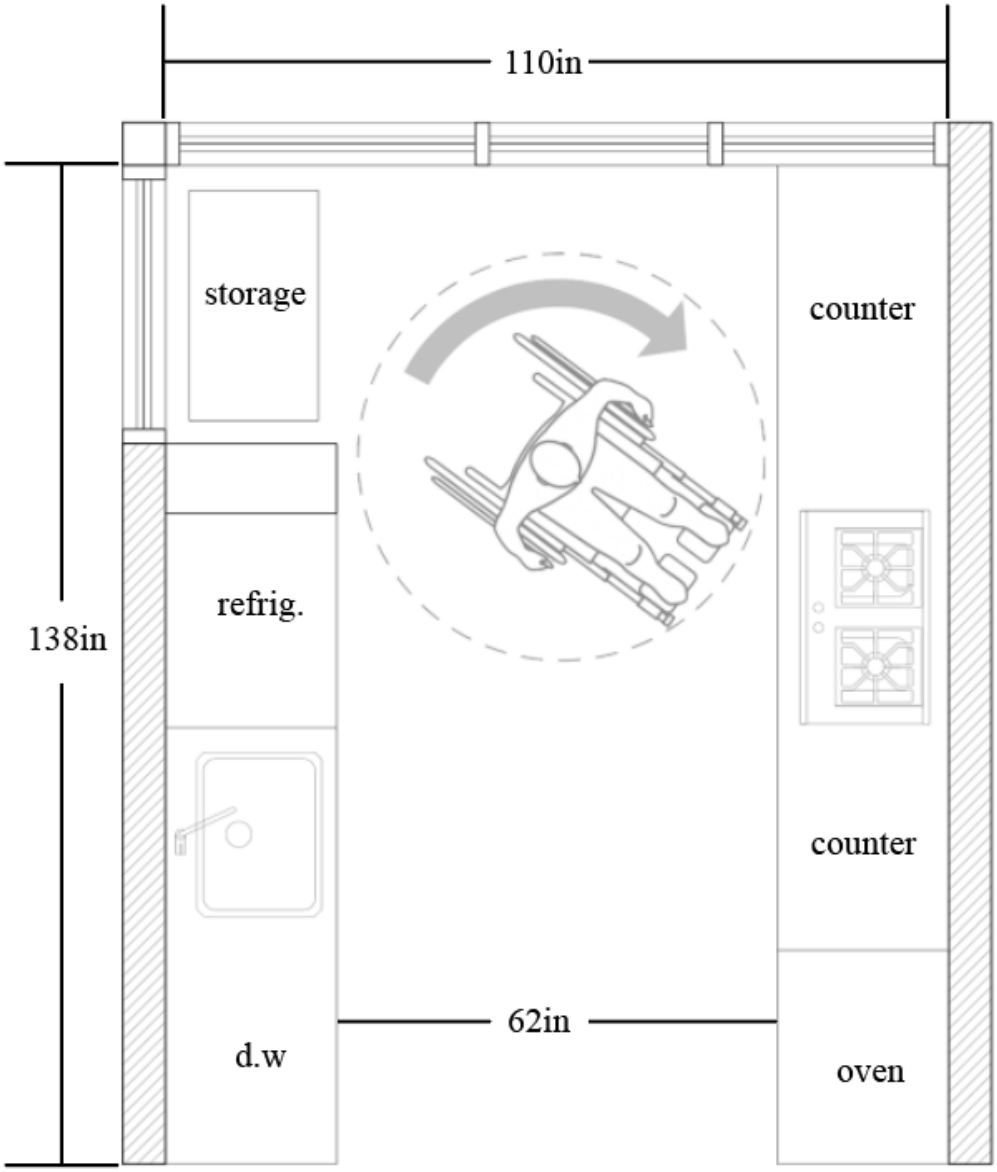


Figure 74 Kitchen Plan After Redesign

4.4 Home Fixture & Furniture Design & Choose

After filling in the user research form and the body dimension form it can be determined the group to which the user belonged. The dimensions that the user needs are for wheelchair user and for above 65 years old female (see Figure 75 and 76). The uncolored parts are requirements and recommendations for all users and are required to be looked at for every user.

<table>
<tr><th colspan="5">Kitchen</th></tr>
<tr><td></td><td>Standard/Principle</td><td colspan="3">User Required</td></tr>
<tr><td rowspan="2">Kitch Counter</td><td rowspan="2"></td><td rowspan="2">Wheelchair User</td><td colspan="2">Other User</td></tr>
<tr><td>Male</td><td>Female</td></tr>
<tr><td rowspan="4">Height</td><td rowspan="4">ADA: 34in max. height. for wheelchair users.

Suitable counter height should be 3in less than elbow height.</td><td rowspan="8">34in max. Height

Addition: At least for one knee space under counter (27in min. height)</td><td>Below 65y
P1~P50:
35in to 39in</td><td>Below 65y
P1~P50:
32in to 36in</td></tr>
<tr><td>Below 65y
P50~P99:
39in to 43in</td><td>Below 65y
P50~P99:
36in to 40in</td></tr>
<tr><td>Above 65y
P1~P50:
33in to 37in</td><td>Above 65y
P1~P50:
31in to 35in</td></tr>
<tr><td>Above 65y
P50~P99:
37in to 41in</td><td>Above 65y
P50~P99:
35in to 38in</td></tr>
<tr><td rowspan="4">Depth</td><td rowspan="4">ANSI: 25in max. depth for wheelchair user.

Suitable counter depth should not exceed the depth of arm grip reach.</td><td>Below 65y
P1~P50:
26in to 29in</td><td>Below 65y
P1~P50:
24in to 26in</td></tr>
<tr><td>Below 65y
P50~P99:
29in to 33in</td><td>Below 65y
P50~P99:
26in to 30in</td></tr>
<tr><td>Above 65y
P1~P50:
21in to 26in</td><td>Above 65y
P1~P50:
21in to 25in</td></tr>
<tr><td>Above 65y
P50~P99:
26in to 28in</td><td>Above 65y
P50~P99:
25in to 28in</td></tr>
<tr><td>Cooktop
Height</td><td colspan="4">Same requirement with counter height</td></tr>
<tr><td>Depth</td><td colspan="4">Same requirement with counter depth</td></tr>
</table>

Figure 75 The Dimensions That User Need - One

<table>
<tr><td>Control Button</td><td colspan="3">All rear-control cooktops should be avoided.
 
Should choose front-control cooktops.
  </td></tr>
<tr><td>Under Conter</td><td>Ensure Accessibility
Reduce Bending/ Scooping
Avoid Squatting</td><td colspan="2">Drawers are more suitable than cabinets, full-extension drawers are good choice.
  </td></tr>
<tr><td rowspan="6">Upper Cabinet</td><td rowspan="6">Accessible Upper Cabinet Placed Height: 15in to 18in from countertop.

Standard Upper Cabinet placed Height: 18in to 22in from countertop.

The height of upper cabinets is all personal preference, but it should not exceed grip reach height.</td><td rowspan="6">Wheelchair User
Upper cabinets are all hard for wheelchair users to access. Consider pull-down cabinets or shelves for easier reach.
  </td><td>Other User
Male</td><td>Female</td></tr>
<tr><td>Below 65y P1~P50: 74in to 82in grip reach height</td><td>Below 65y P1~P50: 68in to 76in grip reach height</td></tr>
<tr><td>Below 65y P50~P99: 82in to 91in grip reach height</td><td>Below 65y P50~P99: 76in to 84in grip reach height</td></tr>
<tr><td>Above 65y P1~P50: 66in to 73in grip reach height</td><td>Above 65y P1~P50: 58in to 69in grip reach height</td></tr>
<tr><td>Above 65y P50~P99: 73in to 78in grip reach height</td><td>Above 65y P50~P99: 69in to 75in grip reach height</td></tr>
<tr><td colspan="2">For shorter users, pull-down cabinets or shelves are also recommended for easier access.</td></tr>
</table>

Figure 76 The Dimensions That User Need - Two

<table>
<tr><td>Range Oven</td><td rowspan="2">Need sufficient approach space, either forward or parallel</td><td>For wheelchair users, recommended to leave knee space beside the oven.
  </td><td>Range ovens are usually installed in a lower position which is difficult for most mobility issues standing people to use.
  </td></tr>
<tr><td>Wall Oven</td><td colspan="2">Wall oven can be a better choice for most people without bending or lifting from lower heights. (Wall ovens can be placed at any height, but for wheelchair user, the oven button shouldn't higher than 48in.)
  </td></tr>
</table>

Figure 77 Figure 76 The Dimensions That User Need - Three

Those can be obtained from the table:

- The counter height should be between 31 in ~34 in.
- The counter depth should not exceed 25 inches.
- Considering the use of a wheelchair in the future, there should be at least 27 inches high and 30 inches wide knee space under the sink and cooktop.

- Before using the wheelchair, the highest level of the storage shelf/cabinet should not exceed 69 inches.
- Considering the use of a wheelchair, the top shelf/cabinet should not exceed 48 inches.
- Pull-down shelves are a good choice for both short people and wheelchair users.
- Wall ovens can reduce bending and lifting from lower heights, but for wheelchair users, the oven button shouldn't be higher than 48 inches.
- The handles and buttons should be simple to operate, which do not require hand gripping, twisting, or pinching.

After getting those data and information from the guideline in Chapter 3, it is time to proceed with the design or selection of furniture and the selection of the kitchen application's position. Since the author wants to show the application and advantages of modular design, the next step will be to follow the Modular Furniture Design Guideline given in Chapter 3 to design modular furniture for the kitchen.

4.5 Modular Furniture Design Application

In this section the author will follow the steps of modular furniture design guideline given in chapter 3 to design modular counter, cabinet and storage shelf for kitchen.

4.5.1 Step One: Decide Module Type

Counter and cabinet will maintain a form for a long period of time and will not change position easily, only when the user's physical condition changes greatly, for example, from non-wheelchair to wheelchair, so the authors will use type of modules without independent function.

The storage shelf can change its position and height at any time according to the user's needs, so it is decided to use the module type of modules with independent function.

4.5.2 Step Two: Divide Function

- Counter and Cabinet

The counter is mainly divided into countertop and base cabinet. Countertop is not a part of modularization because it is directly cut according to the size of customer's needs, so the parts that need to be modularized are base cabinet, upper cabinet and other use cabinets.

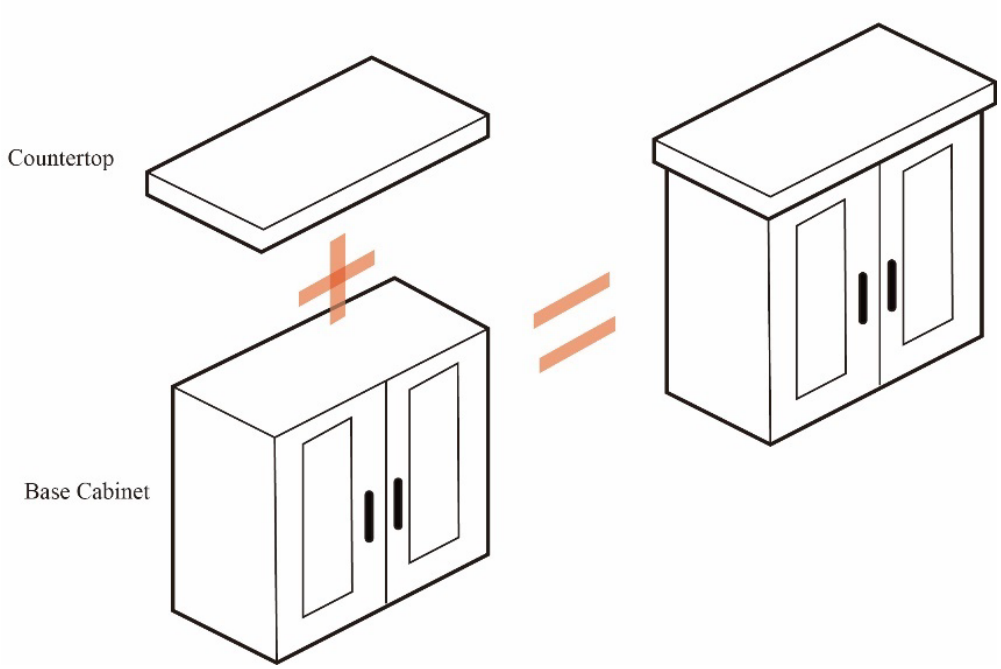


Figure 78 The Counter Constitute

Then according to the type of furniture, the designer starts to divide the function and then according to the function to divide the required modules. Figure 79 shows the functionality of the cabinet and the required modules and parts.

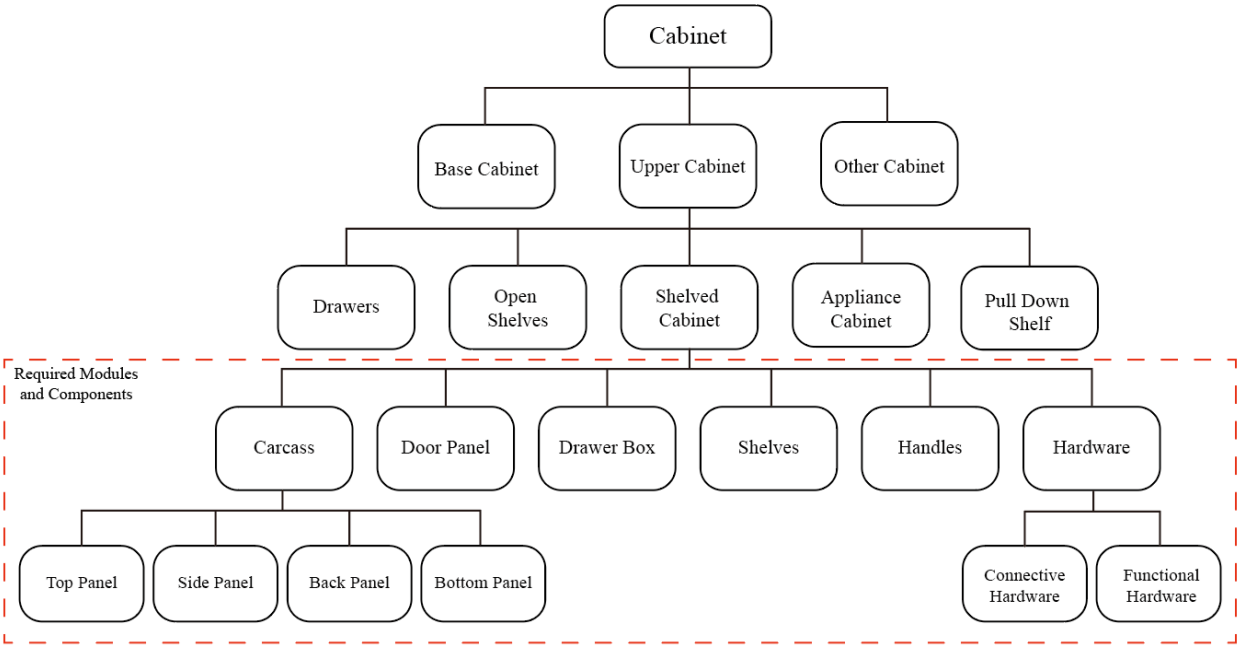


Figure 79 Divide Modules

- Storage Shelf

The module type used in storage shelf is module type with independent function and the necessary basic function is storage. Therefore, the module must provide a certain amount of storage space and the ability to be used independently.

4.5.3 Step Three: Determine Connection Way

- Counter and Cabinet

Counter and Cabinet is mainly about the connection between carcass panels and the connection between carcass and other modules (door, drawer, drawer box, shelves, handles, hardware). Since the counter and cabinet are not to be moved or reorganized frequently, and because of the need for standard hardware, uniform diameter screws are used for the assembly of the carcass and the assembly of the hardware. In addition, considering that the base panels and

shelves may need to be changed several times according to the user's needs, a connection way should be easier to disassemble and assemble.

- Storage Shelf

The purpose of the modularized storage shelf is to be able to be changed and moved at any time according to the user's needs, so the connection method must be easy to assemble and disassemble.

4.5.4 Step Four: Design Module

According to Modular Furniture Design Guideline, modules are designed for multiple and repeated use and can be combined or connected with other modules. Modules need to have the same or consistent interface design and the dimensions of the modules or combined products should comply with the ergonomic standards.

- Counter Modules Design

The part of the counter that needs to be modular is the base cabinet, which consists mainly of the carcass and other functional modules (e.g. drawers, door handles, etc.). The modules that compose the carcass are the top panel, side panels, back panel, and bottom panel.

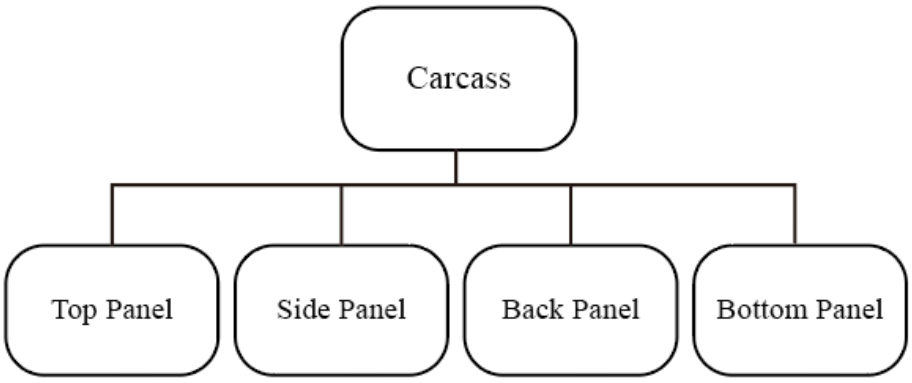


Figure 80 Carcass Compose Part Need

The first step in designing the modules of a carcass is to identify the relevant standard and the required dimensions. From the table of Chapter 3 design approach, we can find that the height of the counter can be categorized according to different human body sizes: the height suitable for wheelchair users and shorter people is usually between 31~34 inches, the height suitable for the majority of people is between 34~37 inches, and the height suitable for taller people is between 37~41 inches. The depth of the counter takes into account wheelchair users. The depth can not exceed 25 inches, and the knee space can not be less than 27 inches high and 30 inches wide. In addition, the thickness of the countertop is usually between 1.2 ~3 inches. Based on the above dimensions, the author has designed the modules that make up the 3 heights of the carcass.

- Side Panel Module

Side panels determine the height of the carcass. The size of the side panel module is 31 inches height, 23.5 inches width and the thickness of the panels is 0.5 inches. The size of the connection hole is 5 mm, and the two rows of 5 mm holes can be installed with other functional modules, according to the user's needs, such as drawers or shelves.

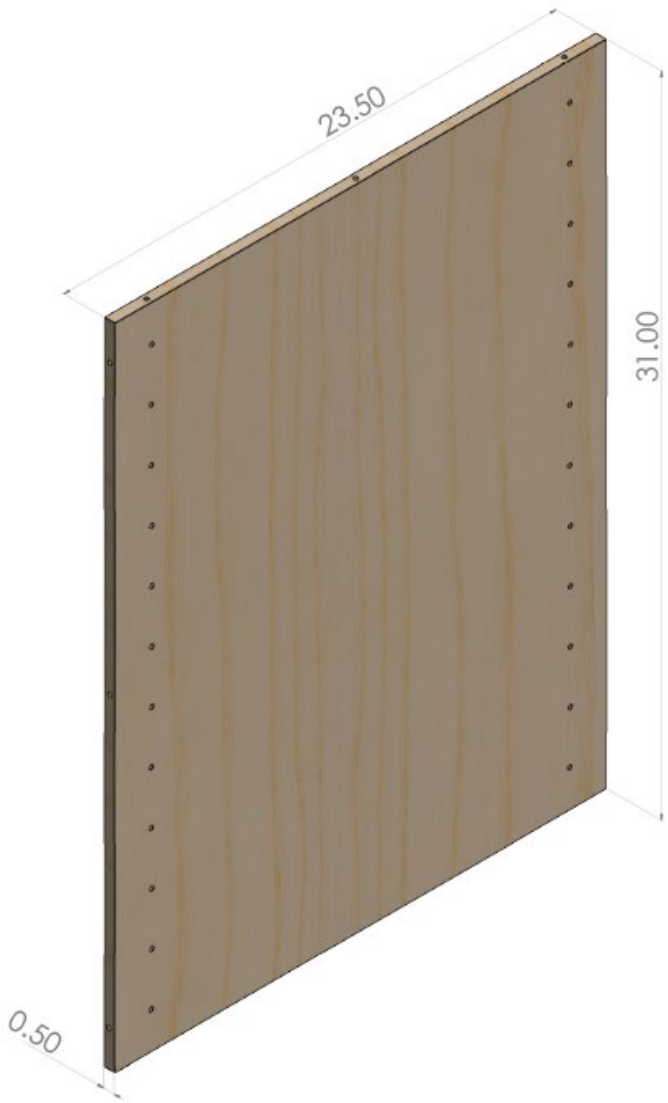


Figure 81 Side Panel Module

- Back Panel Module

Back panels are the same height as side panels, and the width is divided into two sizes, 16 inches and 31 inches, which can be composed of different sizes of carcasses to meet the different needs of users.

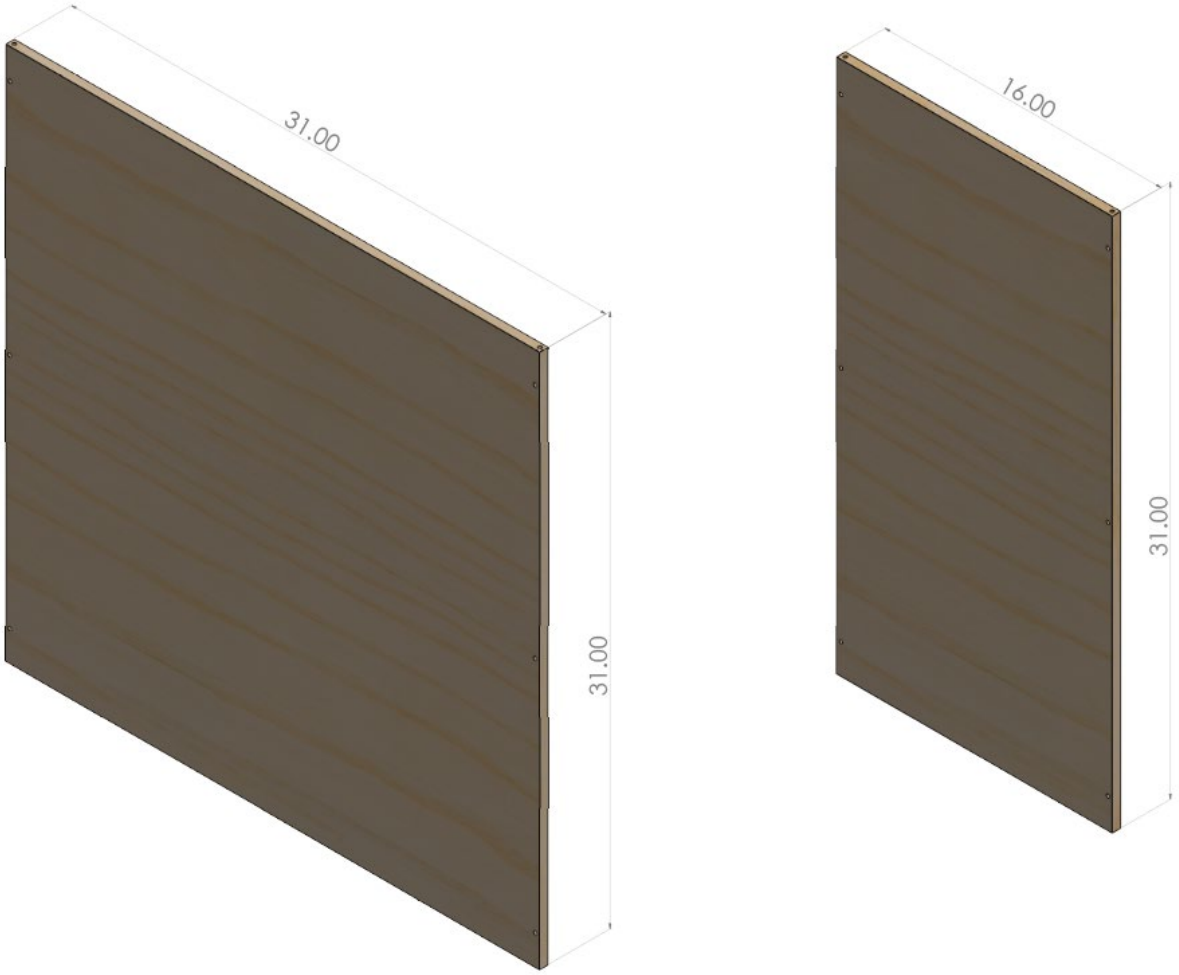


Figure 82 Height Back Panel, 16 inches & 31 inches Width

- Top Panel Module

  The top panel module has two sizes, 24 inches by 31 inches and 24 inches by 16 inches.

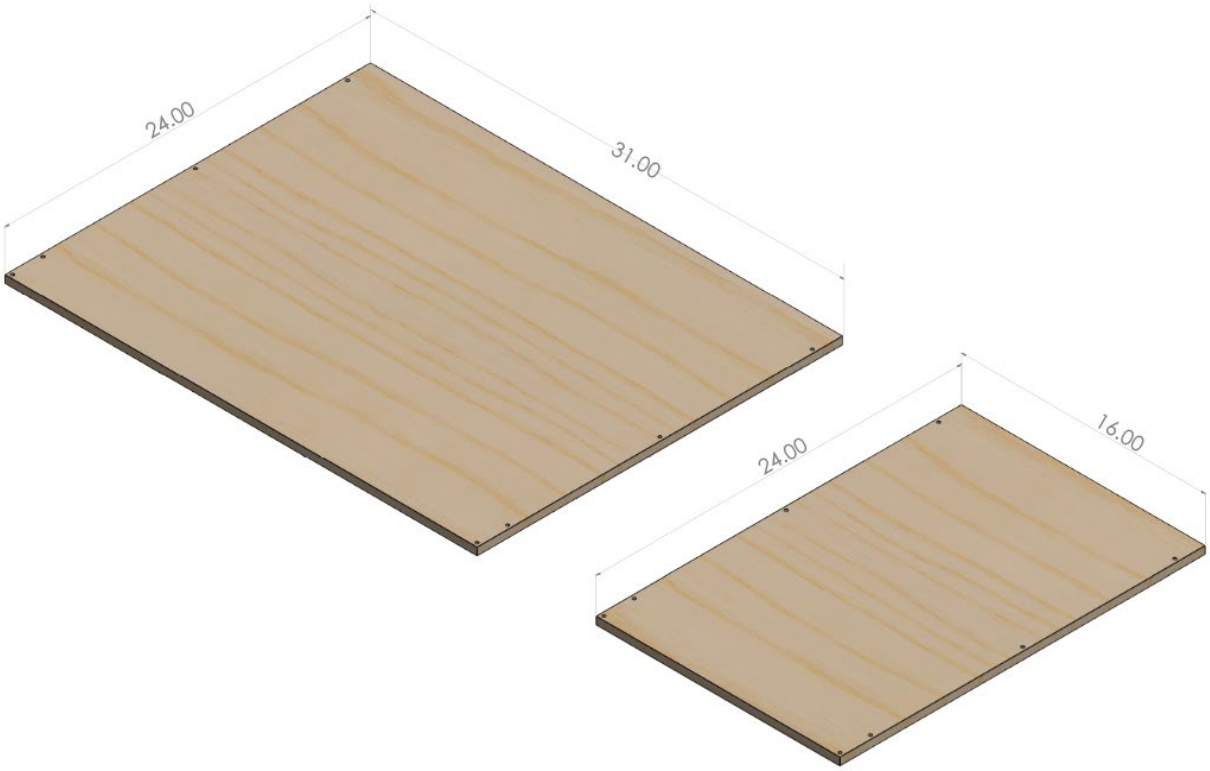


Figure 83 Top Panel Module

- Bottom Panel & Shelf Panel Module

Bottom panels and shelve panels share one module, and the way of connecting the shelf panels and bottom panels is different from the other panels considering that the shelf panels may need to be changed several times according to the user's needs. Two different widths are available, 23.5 inches by 30 inches and 23.5 inches by 15 inches.

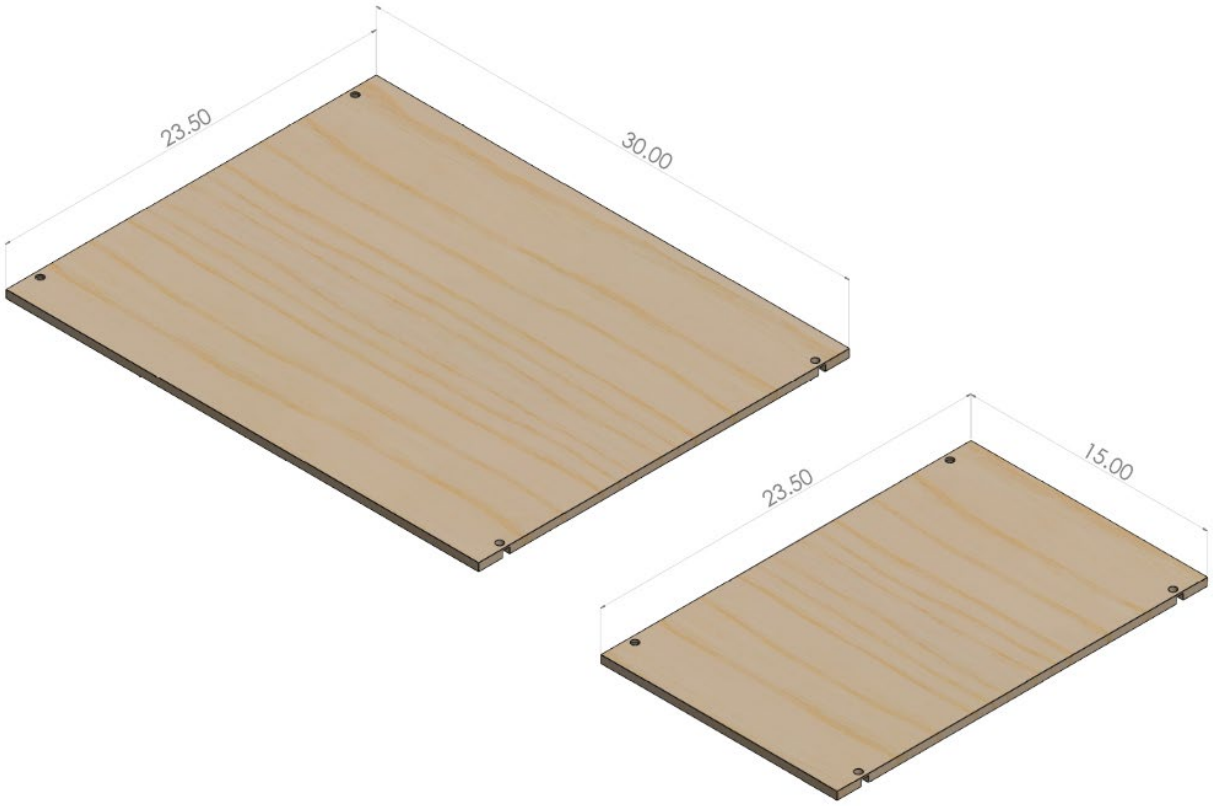


Figure 84 Bottom Panel & Shelf Panel Module

The connections between the panels are as follows:

The side panel, back panel, and top panel are connected with standard-size screws (M5 1 1/4 inch) through the holes at the corresponding positions of the panels. The bottom panel and shelve panel are connected as shown in Figure 86, through the connectors designed by the author, which makes it easier to install and dismantle than screws. Figure 87 provides connection steps.

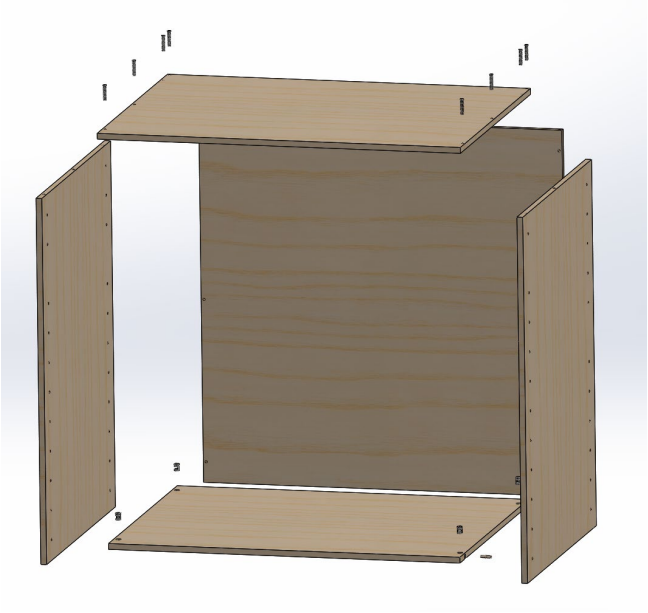


Figure 85 Carcass Combination

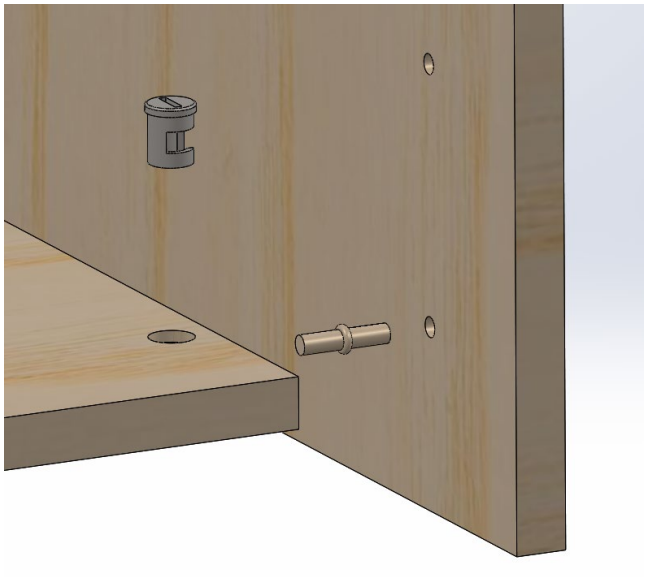


Figure 86 Bottom Panel and Shelf Panel Connect Way

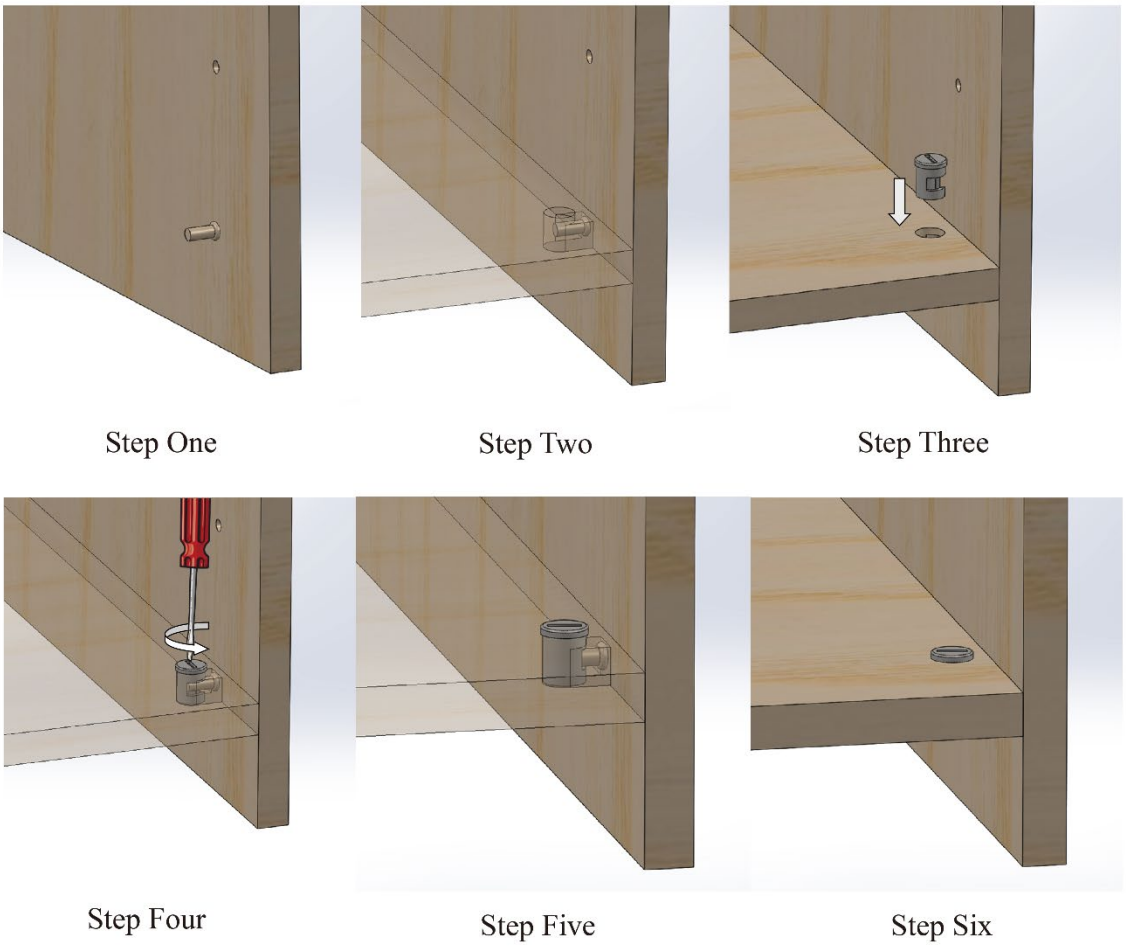


Figure 87 Bottom Panel and Shelf Panel Connect Step

Through the above modules and connections, 2 types of basic carcasses can be assembled, as shown in Figure 88. Standard dishwasher width is usually 18 ~ 24 inches, height is 29 ~ 35 inches, which can fit in 31in wide carcass. Standard oven sizes are usually 24 inches, 27 inches and 30 inches, height is usually from 27 inches to 29 inches, which can also fit in 31 inches wide carcass.

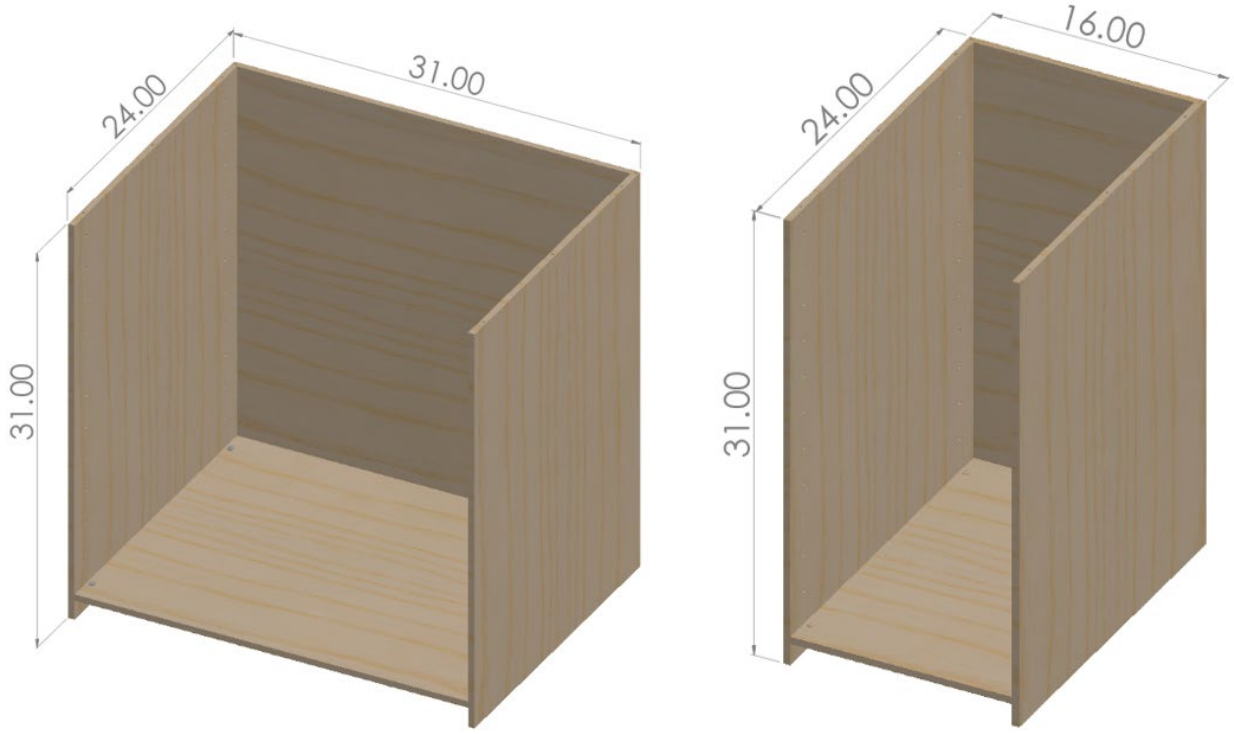


Figure 88 2 Types of Basic Carcasses

Once the base cabinet is assembled, it can be combined with other modules to compose a complete base cabinet according to the user's preference.

- Drawer Box Module

  There are three sizes for different needs.

  For 31 inches wide carcass use:

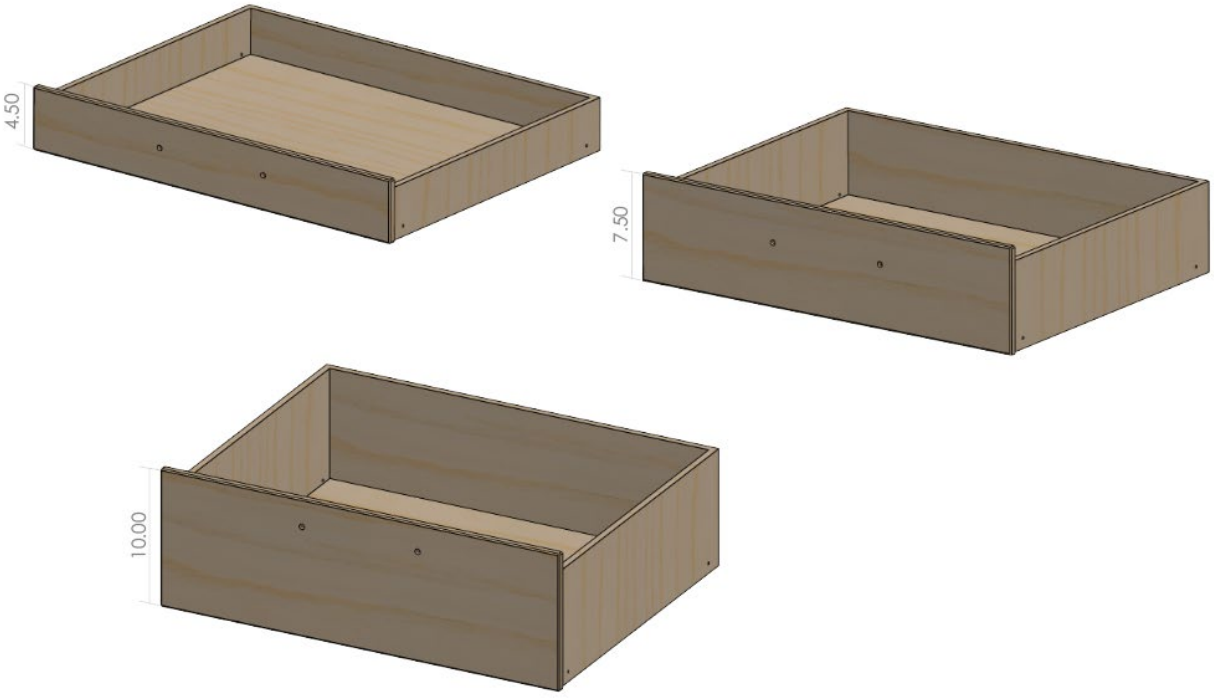


Figure 89 Drawer box module for 31 inches width carcass use

For 16 inches wide carcass use:

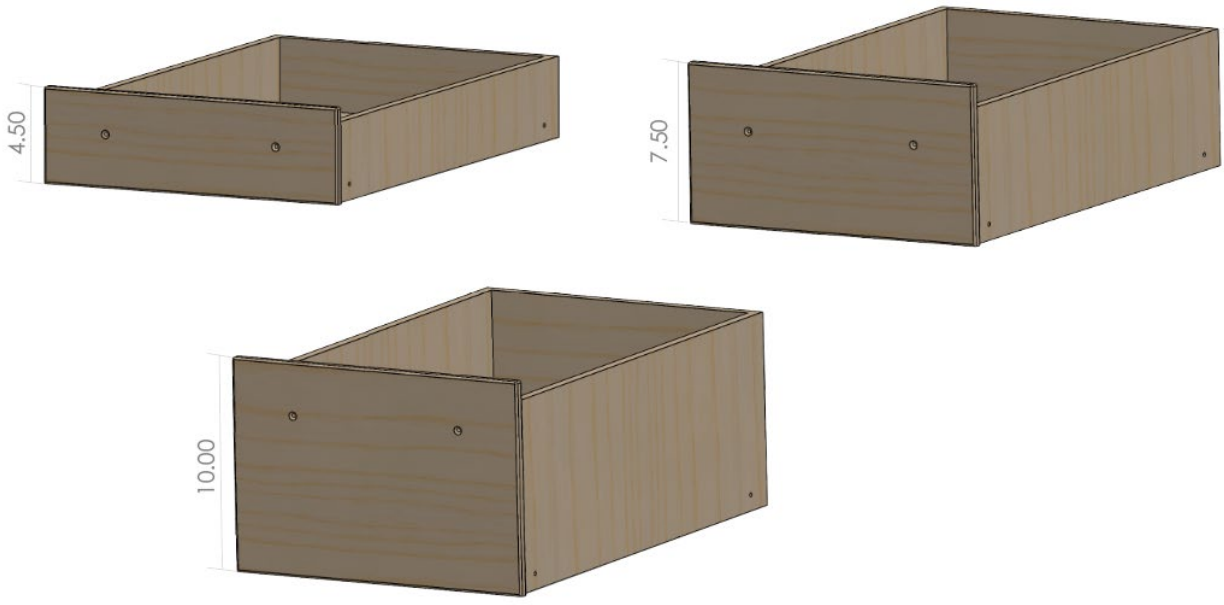


Figure 90 Drawer box module for 16 inches width carcass use

The drawer box module uses 22 inches long standard slide channels for connection and uses M5 ½ inches length screws to attach side panels.

Figure 91 Drawer Box Connector

- Shelves Module

Shelves panel and bottom panel share one module, so they have the same dimensions and connections.

Figure 92 Shelves Module, 30 inches Width

Figure 93 Shelves Module, 15 inches Width

- Door Panel Module

Figure 94 Door Panel Module, 16 inches Width

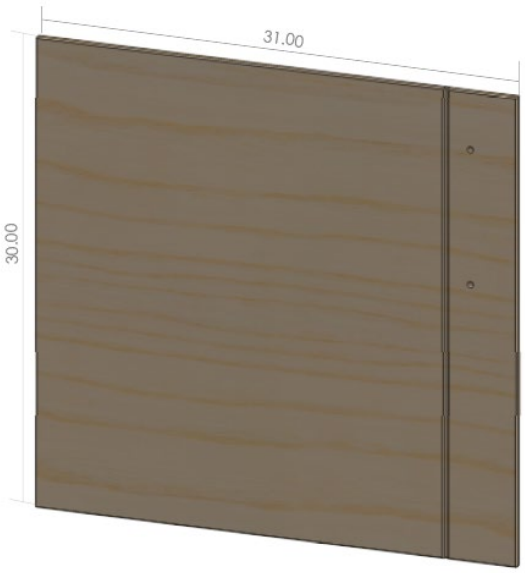


Figure 95 Door Panel Module, 31 inches Width

- Door Handle Module

The Door Handle Module is designed for installation on all door panels and drawer boxes. It uses standard M5 screws that are 1¼ inches in length to connect the handle securely to the door panels and drawer boxes.

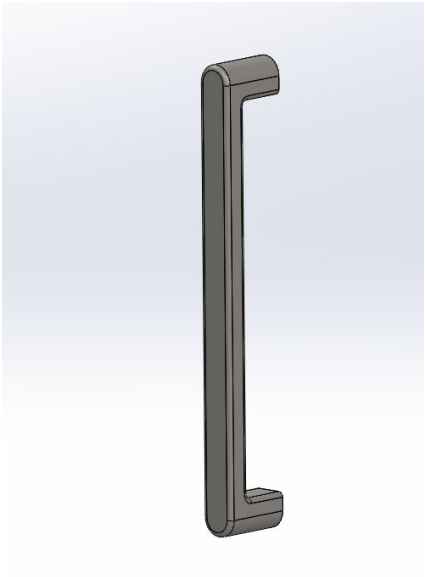


Figure 96 Door Handle Module

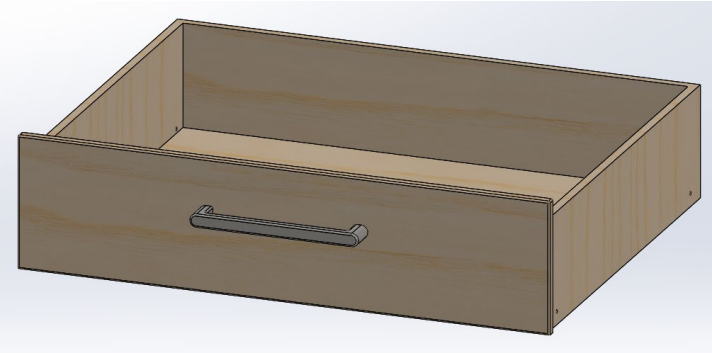


Figure 97 Drawer with Handle

Figure 98 Door with Handle

- Moveable Cabinet Module

Considering the need for knee space for wheelchair users, removing all cabinets under the counter would reduce storage space. To address this, the author has designed a moveable cabinet

that can be shifted within a certain range under countertop. This design not only provides storage space but can also be moved aside when knee space is required for the user. The hardware includes standard sliding tracks and wheel rollers, which are attached using M5 screws. The interior of the moveable cabinet can be customized with shelves or drawers.

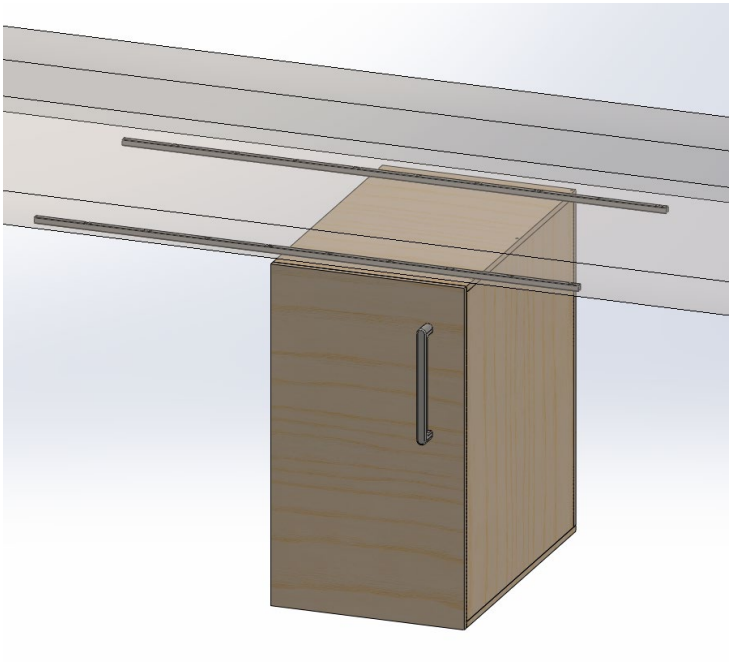


Figure 99 Moveable Cabinet Module Install Under Countertop

Figure 100 Moveable Cabinet Module Connector

Figure 101 Moveable Cabinet with Shelve and Drawer

- Upper Cabinet Modules Design

The depth of upper cabinets typically ranges from 12 inches to 15 inches. If the cabinets are too deep, they can negatively affect the user's experience with the counter below. Based on this data, the author has designed two different sizes of carcasses to accommodate different requirements.

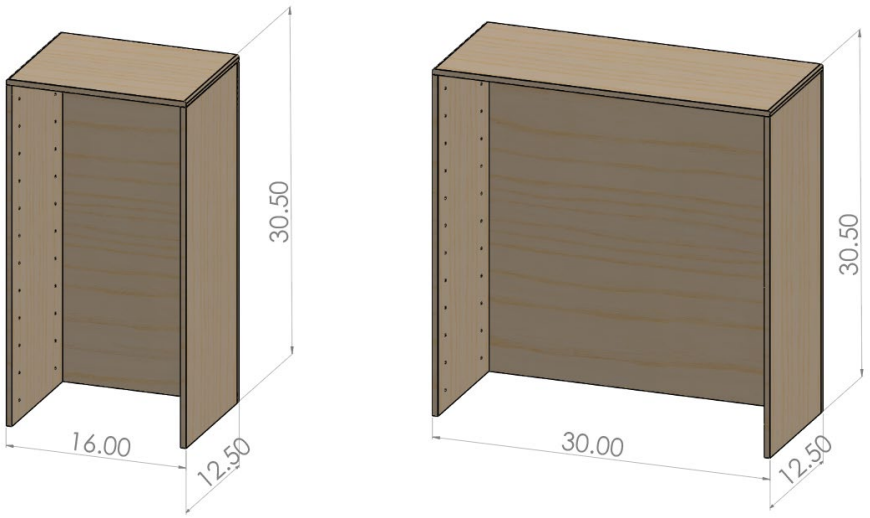


Figure 102 Upper Cabinet Carcass Modules with Two Sizes

Upper cabinets are generally not suitable for drawers, so there are two sizes of shelf modules to correspond with the different sizes of carcasses. The method of connecting these shelves is the same as the counter shelves. The number and placement of the shelves can be adjusted based on user needs.

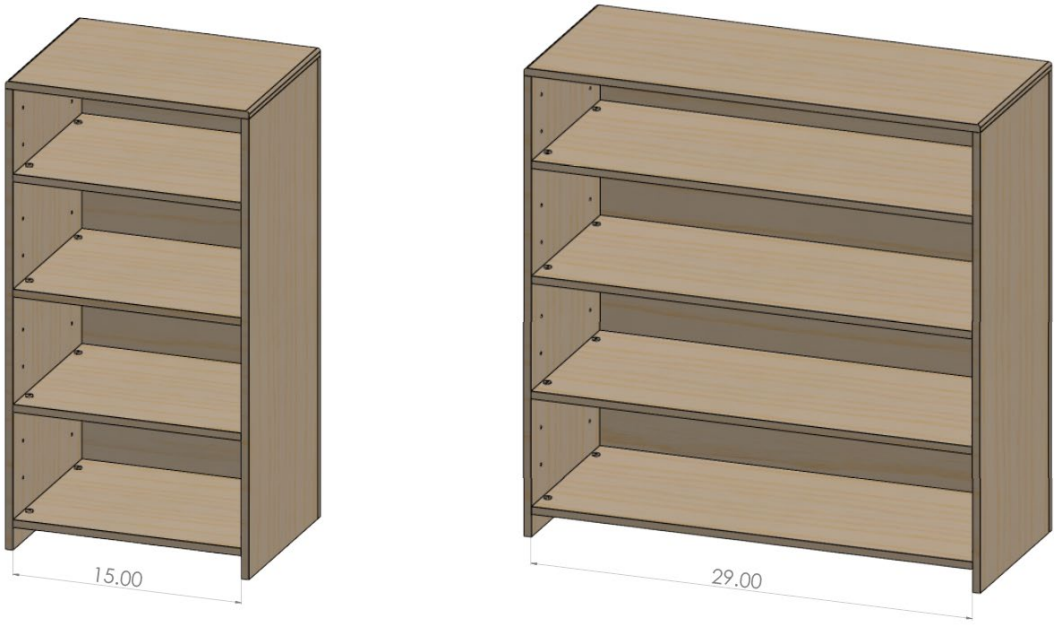


Figure 103 Upper Cabinet with Shelves

Additionally, considering shorter users and wheelchair users, there is an option to install either a 15 inches wide pull-down shelf or a 30 inches wide pull-down shelf. This feature allows for easier access to the contents of higher shelves.

Figure 104 Pull-down Shelf, 15inch & 30inch Wide

The two door panel modules are of the same size, but the placement of the handles varies (left and right). The placement of handles on upper cabinets differs from that on base cabinets due to their positioning. Since upper cabinets are installed higher up, to facilitate easier access, the handles are positioned on the lower part of the door panels. Conversely, base cabinets are located at a lower position, making it more practical to place the handles on the upper part of the door panels.

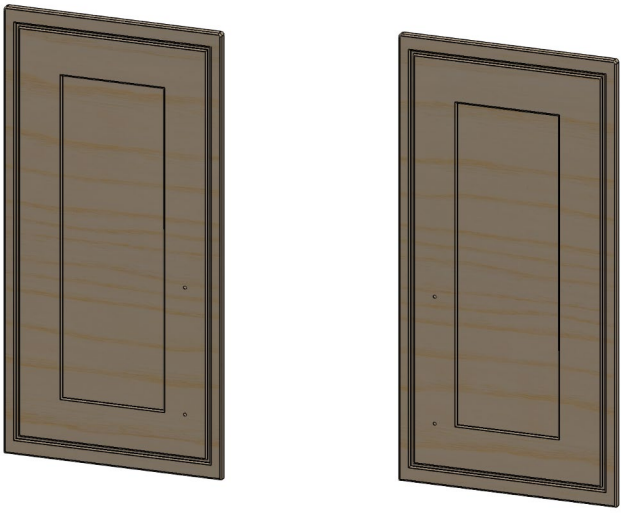


Figure 105 Upper Cabinet Door Panel Modules

The handles used are the same as those on the counter; Figure 106 shows two sizes of upper cabinet which are assembled according to the above module.

Figure 106 Upper Cabinet

- Stroage Shelf Modules Design

		Wheelchair User (Approach Range)		Other User (High Reach Range)	
				Male	Female
Storage Height	ADA: For forward approach, 48in max. height of high reach; 15in min. of low reach. For side approach, 54in max. of high reach; 9in min. of low reach. For Others: high reach cannot exceed vertical grip reach, low reach cannot less than 15in.	Forward: Below P5: 15in min. to 40in max.	Side: Below P5: 9in min. to 51in max.	Below 65y P1~P50: 74in to 82in grip reach height	Below 65y P1~P50: 68in to 76in grip reach height
				Below 65y P50~P99: 82in to 91in grip reach height	Below 65y P50~P99: 76in to 84in grip reach height
		P5~P95: 15in min. to 48in max.	P5~P95: 9in min. to 54in max.	Above 65y P1~P50: 66in to 73in grip reach height	Above 65y P1~P50: 58in to 69in grip reach height
				Above 65y P50~P99: 73in to 78in grip reach height	Above 65y P50~P99: 69in to 75in grip reach height

Figure 107 Storage Dimension Requirements

From the Home Fixture & Furniture Design & Choose guidelines presented in Chapter 3, it is noted that the minimum reachable height for wheelchair users is 9 inches, while the maximum reachable height varies depending on age and gender. To accommodate these variations, the author has designed modular storage shelves that can be adjusted in height to meet the different needs of users. Each module can also be used independently, this shelf not just for kitchen use, but for any space requiring storage shelves.

The modular storage shelf consists of two modules: shelves and drawers. The shelf module has a height of 11 inches, and the drawer module handle is set at a height of 14 inches, ensuring that both modules are within a reachable range even when used independently.

Figure 108 Shelve Module of Modular Storage Shelves

Figure 109 Drawer Module of Modular Storage Shelves

The modules are connected in an easy-to-assemble and disassemble way as shown in the figure below.

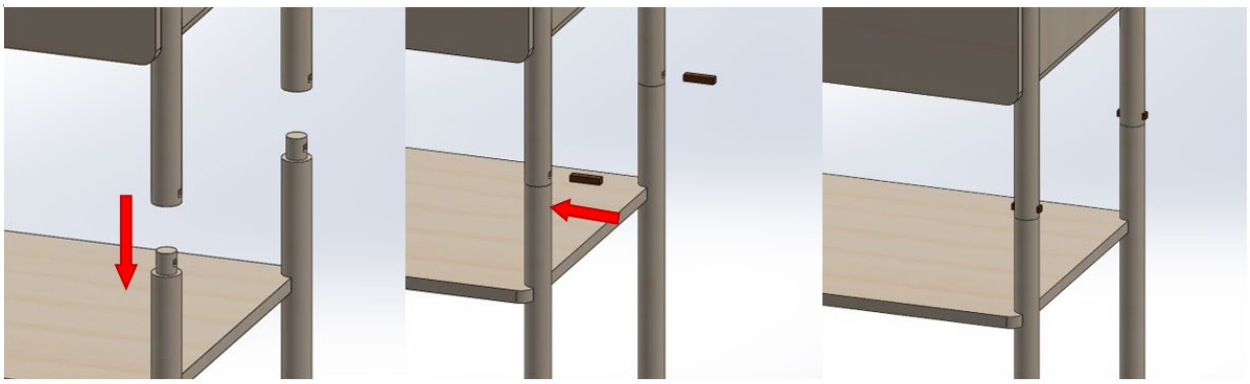


Figure 110 Step of Assemble Modular Storage Shelves

There are the caps for the top of module or individual use module, see Figure 111.

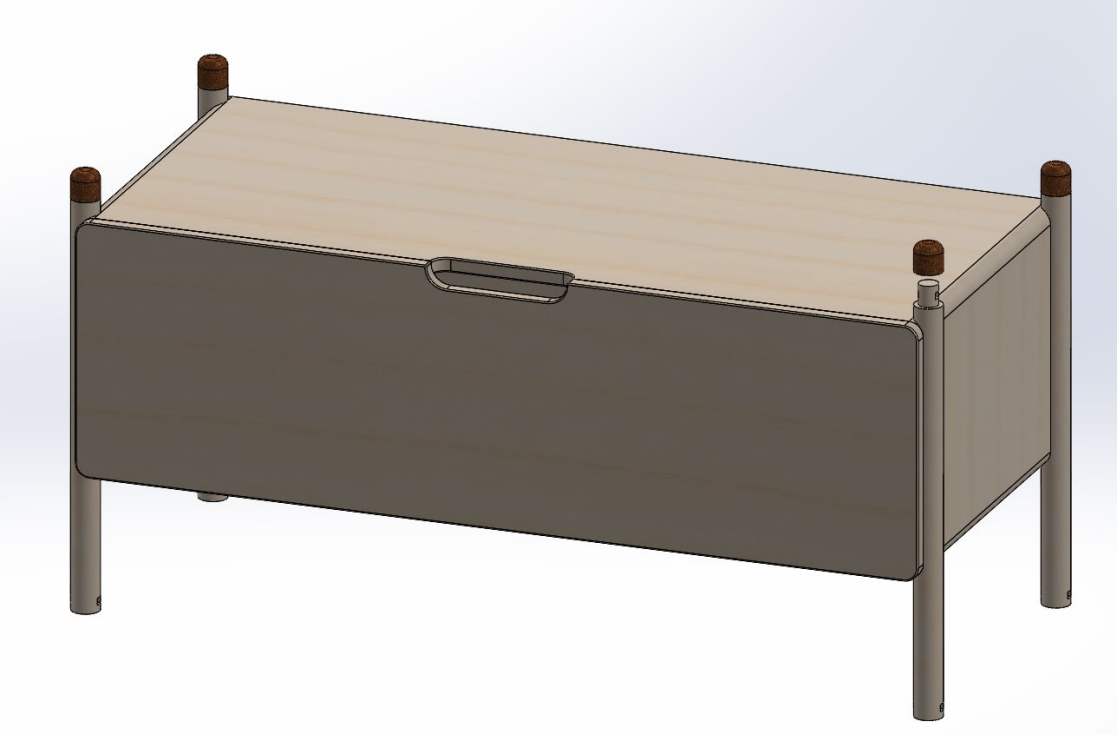


Figure 111 Drawer Module with Cap

Users can combine the different modules to suit their needs (see Figure 112).

Figure 112 The Different Way to Assemble

- Material Considerations

Material Consideration	Should choose **durable materials with a smooth surface** to ensure long-term use and accurate assembly and combination.	
	As these modules may need frequent change, **lighter materials** are recommended for easy move and combination.	As these modules often require assembly of multiple pieces to provide function and stability; the materials need to be **sturdy and durable**.

Figure 113 Material Chooses Considerations

According to the guidelines, the modular counter and modular upper cabinets can use 0.5 inches MDF with a wood grain finish as the material. For the modular storage shelves, hard maple is selected as the material of choice. Hard maple is lightweight yet sturdy and durable, making it suitable for long-term use.

4.5.5 Step Five: Module Combination

- Before use wheelchair:

Based on user body data, the 31 inches height carcass has been selected for the base cabinets. Then, the user can choose the other modules depending on their performance. Figure 114 shows the final look.

Figure 114 Kitchen Before Use Wheelchair

The counter utilizes a total of four carcasses each measuring 31 inches by 31 inches by 24 inches, and three carcasses each measuring 16 inches by 31 inches by 24 inches. It also includes two door panels measuring 31 inches by 30 inches and three door panels measuring 16 inches by 30 inches. Additionally, users have chosen corresponding drawer boxes and shelves based on her needs.

The upper cabinet consists of two carcasses each measuring 30 inches by 12 inches by 30.5 inches and one carcass measuring 16 inches by 12 inches by 30.5 inches, along with five door panel modules. There is also a customized component above the range hood, adapted from a 30 inches wide carcass to accommodate space for the range hood.

Considering that a wall oven is more suitable for user accessibility, the author used existing modules to assemble a wall oven cabinet, as shown in Figure 115 below.

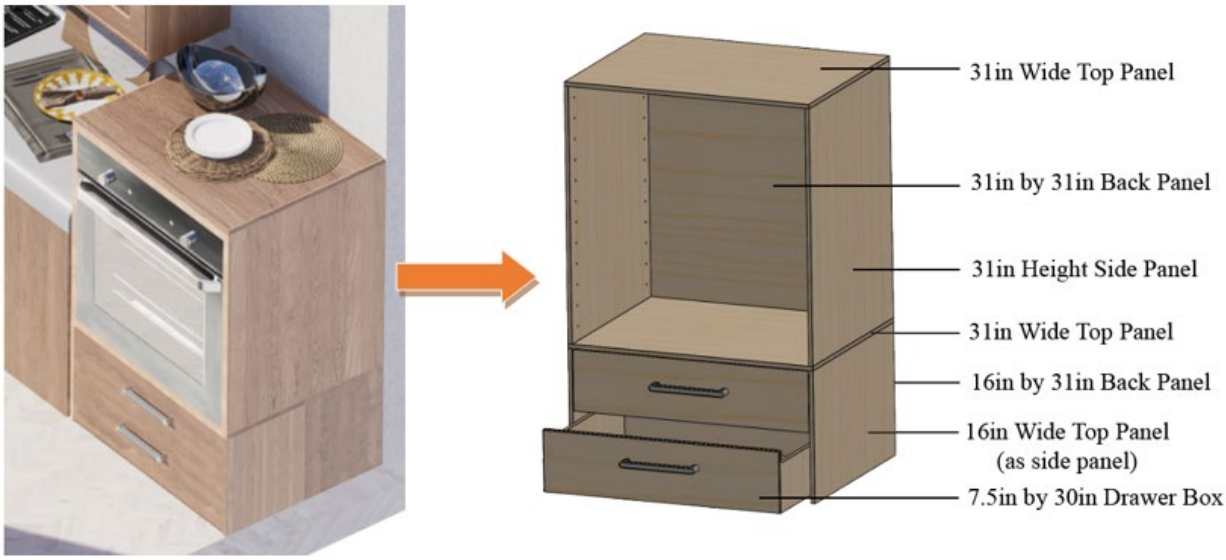


Figure 115 Wall Oven Cabinet

- When use wheelchair:

The advantage of modular design becomes apparent when the user's physical condition changes. Instead of having to dismantle or alter the entire cabinetry, only specific modules need to be replaced or removed to accommodate the user's changing needs.

Cook Area: By removing three base cabinets totaling 63 inches in width and replacing them with two moveable cabinet modules totaling 32 inches in width, flexibility is greatly enhanced. When the cooktop is needed, the moveable cabinets can be shifted to the side of the oven, and when the oven is in use, the cabinets can be moved under the cooktop.

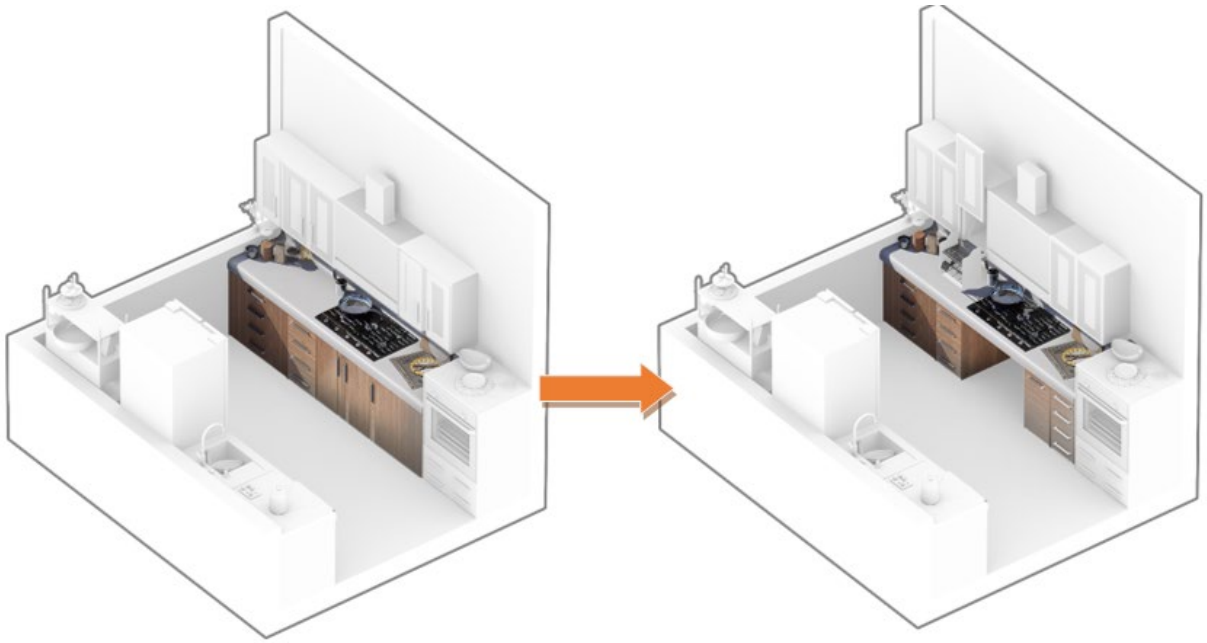


Figure 116 Cook Area Changing

Sink Area: Adjusting the module under the sink is really easy and quick, which is a significant advantage of modular design. By simply removing the door panel and the bottom panel, enough knee space can be provided for wheelchair users.

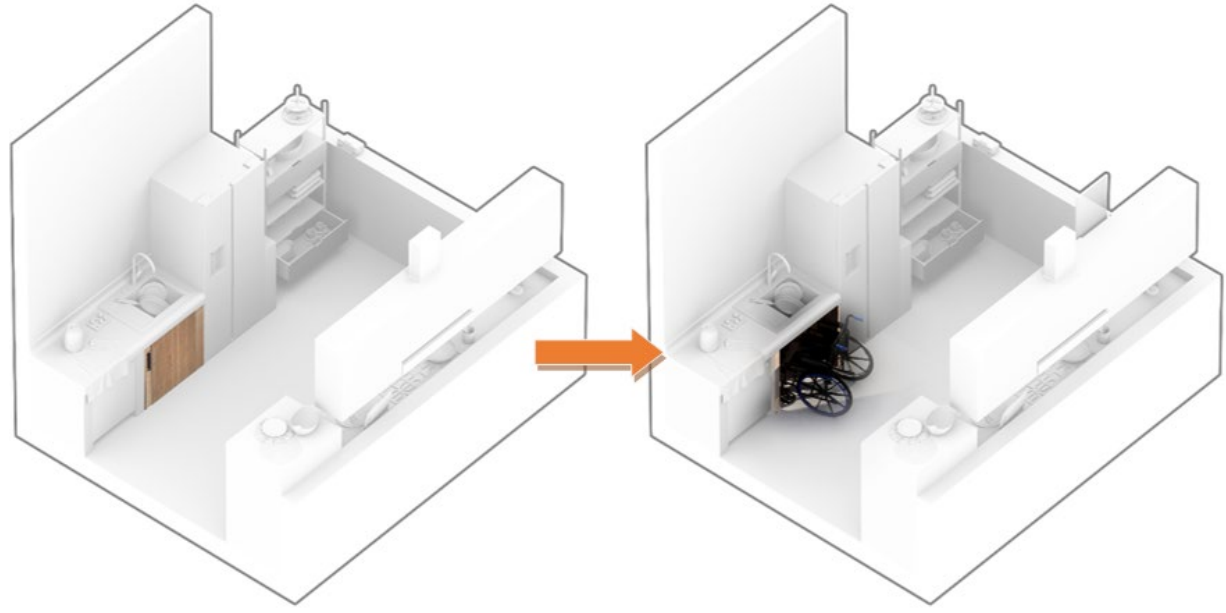


Figure 117 Sink Area Changing

Upper Cabinet: When using a wheelchair, the reachable range is reduced, making upper cabinets difficult to access. Therefore, the user chooses to remove the bottom panel and install a pull-down shelf into the upper cabinet.

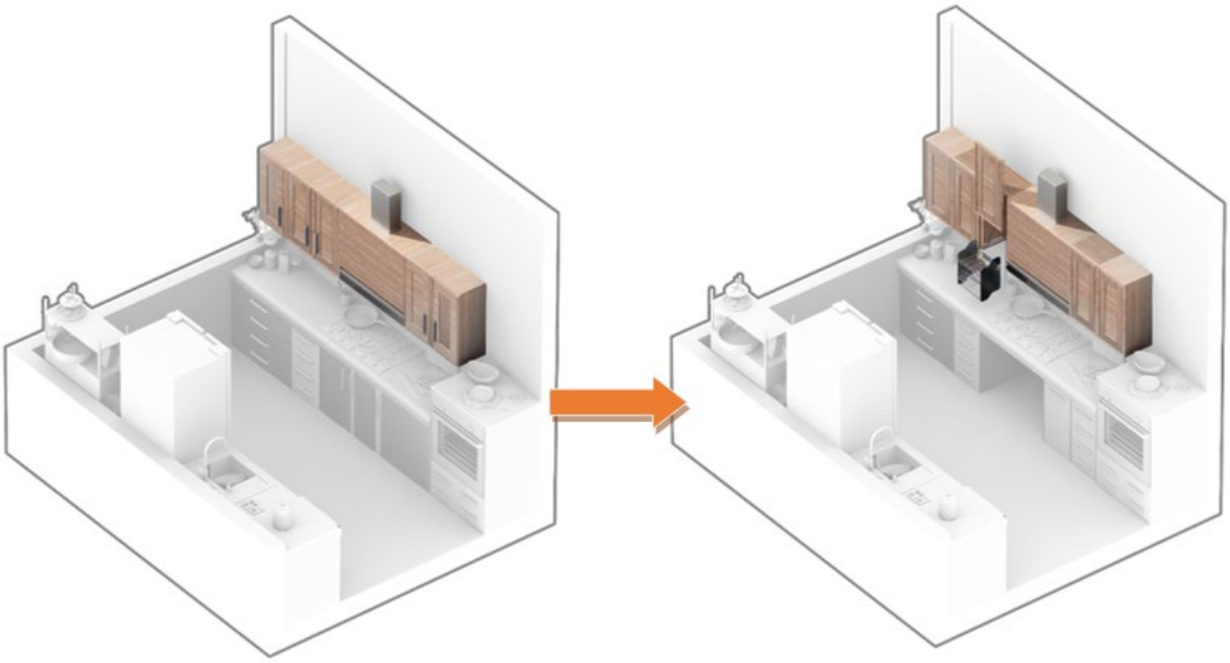


Figure 118 Upper Cabinet Change

Overall look:

Figure 119 Kitchen When Use Wheelchair

4.6 Final Rendering

- Before use wheelchair

Figure 120 Before use wheelchair – Cook Side

Figure 121 Before use wheelchair – Sink Side

- When using wheelchair

Figure 122 When Using Wheelchair – Cook Side one

Figure 123 When Using Wheelchair – Cook Side two

Figure 124 When use wheelchair – Sink Side

- Modular Storage Shelf

Figure 125 Modular Storage Shelf Rendering

Chapter 5 Conclusion

The author believes that everyone has the right to choose the lifestyle they desire, and people with mobility issues should also have access to comfortable and independent living environments. Although the ADA Standards provide certain specifications and constraints for basic living facilities, they are not enough to create a comfortable living space. Therefore, the author has developed a design approach that begins with understanding the specific needs of users, selecting appropriate body measurements to use for space planning, and choosing home fixtures and furniture. This approach also includes the application of modular design to create more comfortable and convenient living environments for people with mobility impairments.

The thesis developed a user survey to help designers better understand their user; five physical data tables for different populations to facilitate designers in finding the appropriate dimensions for users; a space planning checklist to assist designers in gathering necessary data when designing spaces and to check if current designs comply with relevant regulations; home fixture and furniture guidelines for both choosing and designing to help designers understand fixtures and furniture suitable for various groups; and finally, a modular design guideline that gives the steps for designing modular furniture, for designers to know how to construct such items effectively.

This study and its data are limited to the United States, but many people around the world with mobility issues are troubled by unsuitable living environments. More comprehensive research is needed to assist people in other regions.

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