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Requirements for a Wheelchair Project

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ABSTRACT

The global population of people aged 80 or older has increased over the past few decades. In 2017, the United Nations estimated that 137 million people were in this age group, with projections that this number will triple by 2050. To ensure a safe and accessible life, the wheelchair is among the most in-demand products. Each country has specific bodies that establish design standards and regulate the products offered on the market, though the effectiveness of these bodies may vary. The Brazilian market is among the top five countries globally in demand for this apparatus. The study reviews the standards, laws, and regulations applied abroad, emphasizing the design and its methodology. In the literature review, among several approaches, the "Barrier-free Project" approach was developed to prevent barriers from existing in the design of equipment, buildings, and urban areas. The basis of philosophy, architecture, and universal urbanism is the possibility of adapting products and spaces to serve people with different capabilities and skills without needing specific adaptation. The cost of the product was also considered to meet the technical requirements of the product. This paper presents the standards impacting wheelchair design, focusing on international requirements and regulations while proposing requirements to reduce costs and enhance aesthetic appeal. Some requirements are classified as mandatory, while others are considered essential to make the product more attractive and competitive.

Keywords: Wheelchair, Product design, Design standards, Universal projects, Guidelines

INTRODUCTION

The global wheelchair market has experienced significant growth, driven by aging populations, chronic conditions, and increased awareness of inclusivity. In 2023, the United States led the market at USD 4 billion, followed by the European Union (USD 3 billion) and China (USD 2.5 billion) (Grand View Research, 2024). Japan reported USD 1.5 billion, while India (USD 200–300 million) and Brazil (USD 300–400 million) ranked among the top five consumers, with Brazil producing approximately 400,000 wheelchairs annually (Statista, 2024). As Brazil's aging population increased by 57.4% from 2010 to 2022, the demand for accessibility and health policies has continued to rise (IBGE, 2023). According to the World Health Organization (WHO), 10% of the population in developed countries has a

disability, while in developing nations, this rate reaches 12–15%, with 20% experiencing physical disabilities. In Brazil, 14.5% of the population (about 30.8 million people) has some form of disability, and over 8 million report permanent mobility impairments requiring wheelchairs (IBGE, 2000; IBGE, 2023).

Market preferences vary by region; the U.S., the EU, and Japan prioritize motorized and technologically advanced wheelchairs. Brazil, China, and India predominantly use manual models, though demand for motorized options is increasing (Frost & Sullivan, 2024). Globally, wheelchair production adheres to ISO 7176 safety and performance standards, IEC regulations for motorized models, and country-specific certifications, such as FDA (U.S.), ANSI/RESNA (U.S.), CE Marking (EU), PMDA (Japan), Health Canada, and TGA (Australia) (ISO, 2023; FDA, 2023; CE, 2023; PMDA, 2023; Health Canada, 2023; TGA, 2023).

In Brazil, wheelchairs must comply with ANVISA regulations for medical devices and with the accessibility standards established by ABNT NBR 9050 (ANVISA, 2023; ABNT, 2024). The Brazilian National Institute of Metrology, Quality, and Technology (INMETRO) issued Ordinance No. 334 in 2010, which approved the Technical Quality Regulation for Wheelchairs. This regulation established mandatory requirements for the certification of wheelchairs in Brazil. Among the technical standards referenced for this certification is ABNT NBR ISO 7176, which is based on the international ISO 7176 standard. These regulations influence both domestic and export-oriented wheelchair design. According to Estorilio et al. (2017), it is essential to highlight that product design is a key factor in technology transfer, affecting efficiency, cost, and the final product's quality.

In 2025, engineering professionals face challenges in developing universally functional and accessible products, regardless of users' motor, sensory, or cognitive abilities. Prado (1997) noted that urban environments still posed visible and invisible barriers to wheelchair users. Invisible barriers stem from societal perceptions, which can be addressed through design innovation. A notable example is the "Confetti" prosthetic leg cover by Furf Design Studio in Brazil, which transformed prosthetics into fashionable, customizable accessories. In contrast, visible barriers relate to physical accessibility constraints, necessitating adherence to national and international regulations.

Santoso (2023) investigated the experiences of six wheelchair users in facing physical and non-physical barriers in public spaces. The analysis focused on three main topics:

- Accessibility barriers include steep ramps, inaccessible restrooms, negative public attitudes, and lack of information.
- Strategies to overcome barriers, including planning alternative routes and seeking assistance.
- Users 'functional capacity levels, which ranged from independence to dependence, influenced how they addressed obstacles.

The study concluded that, despite the challenges, wheelchair users develop strategies to navigate urban environments, highlighting the need for improved accessibility and greater public awareness.

Regarding cost accessibility, wheelchair prices significantly impact their appearance, robustness, and features. Lower-income individuals face more significant limitations in overcoming visible and invisible barriers. Bertoncello and Gomes (2002) argue that folding manual wheelchairs have evolved slowly, and products for individuals with disabilities remain underexplored in health and technology. They identify a gap in the supply of wheelchairs, classifying them based on technological complexity. Furthermore, not all models meet INMETRO (National Institute of Metrology, Standardization, and Industrial Quality) requirements. INMETRO tested eight manual wheelchair brands (75–100 kg capacity), all failing. This evaluation, published in the "Analysis Report on Wheelchairs, INMETRO Product Analysis Program" (June 2013), followed the Mandatory Certification for Wheelchairs established by INMETRO and MDIC (Ordinance No. 334, August 24, 2010). However, no recent INMETRO wheelchair analyses have been identified, leaving Brazil's current state of compliance uncertain in 2025.

A Feasibility and Impact Study (FIS) examined national and international standards to define safety requirements and testing methods for wheelchairs. INMETRO assessed mechanical resistance, footrests, armrests, seat padding, dimensions, stability, brake systems, and durability, considering ISO 7176 standards, which consist of 26 parts, though only six are mandatory for INMETRO certification. Additionally, NBR 9050 defines technical accessibility criteria for wheelchair use in public spaces.

No study comprehensively addresses regulatory compliance while incorporating user preferences for an aesthetically appealing, barrier-free, and cost-accessible wheelchair in Brazil. Costa and Filho (2001) proposed a low-cost wheelchair design method without considering INMETRO standards or invisible barriers. Similarly, Lima et al. (2016) developed a conceptual design aligned with INMETRO requirements without advancing toward a detailed, aesthetically refined product.

Other studies address wheelchair design using different approaches from this paper. Petrus (2017) emphasizes the importance of considering specific environmental conditions, such as uneven terrain and harsh climates, proposing requirements for robustness and durability. Zhang et al. (2021) explore the challenges faced by powered wheelchairs in high-density areas, focusing on maneuverability, sensors, and safety. Ahmed et al. (2021) present a multifunctional technological solution with various control modes and health monitoring, aiming at user autonomy and safety. Ebrahimi et al. (2016) discuss how ergonomics, comfort, and mobility influence quality of life, proposing a design tailored to the individual needs of users but without providing specific technical standards.

In contrast, this paper adopts a normative and methodological approach focused on the Brazilian market, one of the largest consumers of wheelchairs worldwide. It reviews international standards and regulations impacting wheelchair design, emphasizing design methodology and universal design

principles. Unlike the previous studies, which highlight specific technical aspects, this paper classifies requirements as mandatory and desirable, considering cost and aesthetic appeal. Additionally, it emphasizes the importance of adapting products and spaces from the outset, aligning with the principles of the "Barrier-free Project."

Thus, this study offers a comprehensive regulatory landscape analysis, highlighting international and Brazilian standards. It proposes design solutions that reduce costs and enhance aesthetic value, integrating Universal Design principles to address users' diverse needs while minimizing visible and invisible barriers. This approach aims to contribute to developing a more inclusive and functional wheelchair design tailored to Brazil's unique market needs.

RESEARCH METHODOLOGY

Aiming to present the standards that impact wheelchair design, focusing on international requirements and the regulations in force in Brazil, including technical requirements to reduce costs and enhance aesthetic appeal, the study primarily relied on literature reviews. The topics reviewed included Universal Design, existing standards for wheelchairs, and product design methodology, as Pahl et al. (2005) outlined, detailing the phases and activities involved up to the conceptual design phase.

Standards that establish rules for products and urban infrastructure to promote accessibility for all were identified. From these, only those that directly or indirectly affect wheelchair design were selected for this study. Product cost was also considered when incorporating it into the technical requirements of the product. Regarding the aesthetic appeal of the product, to reduce invisible barriers, this factor was also evaluated to encourage designers to rethink the traditional concepts of wheelchair design.

UNIVERSAL DESIGN

In 1963, the "Barrier-Free Project" was developed in the United States to eliminate barriers in the design of equipment, buildings, and urban areas. Over time, this concept evolved into what is now known as "Universal Design", which is based on respect for human diversity and the inclusion of all individuals in different activities, regardless of age or ability. Universal Design seeks to endow spaces with qualities that benefit everyone (Mace, 1997). The foundation of universal philosophy, architecture, and urbanism is the ability to adapt products and spaces to serve the most significant percentage of people with diverse capacities and skills without needing specific adaptations. To achieve this, several principles are recommended, such as:

- Accommodating a wide anthropometric range: Ensuring products and spaces cater to individuals of different physical standards or situations, paying attention to limits of action and manual or visual reach.
- Reducing the amount of energy required: Minimizing the effort required to use products and the environment.

- Making environments and products more comprehensible: Designing for individuals with special needs (Connell et al., 1997).
  The application of seven principles is recommended for developing spaces and products, as outlined by Mace (1997) and Steinfeld & Maisel (2012). These are:

1. Equitable use: Products should be usable by people with diverse abilities.
2. Flexible use: Products should accommodate various preferences and abilities.
3. Simple and intuitive use: Products should be easy to understand, regardless of the user's experience, knowledge, language skills, or concentration levels.
4. Perceptible information: Products should provide the necessary information to users, regardless of sensory abilities or environmental conditions.
5. Tolerance for error: Universal Design minimizes risks and consequences of accidental or unintentional actions.
6. Low physical effort: Products should be used efficiently and comfortably with minimal effort.
7. Size and space for approach and use: Designs should consider appropriate dimensions and spaces to ensure access, manipulation, and use regardless of physical size, posture, or mobility.
   While Universal Design aims to expand the concept of accessibility by creating solutions that meet legal requirements and make products and spaces more inclusive, accessibility standards provide the legal and technical foundation to ensure these spaces and products achieve a minimum level of functionality and inclusion for individuals with disabilities. The following section provides a review of these standards.

STANDARDS WITH IMPACT ON THE DESIGN OF A WHEELCHAIR

Considering that a wheelchair interacts with its environment, standards related to public spaces, elevators, and transportation systems are critical to this analysis. An analysis of Brazilian standards identified 15 relevant norms. These were grouped into five accessibility categories: Urban Environments and Infrastructure, Transportation Vehicles, Specific Requirements for Wheelchairs, Legislation, and Terminology and Definitions. They include:

Urban Environments and Infrastructure: NBR 9050:2015; NBR 13994:2018; NBR 15655:2008; NBR 15250:2005.

Transportation Vehicles: NBR 14020:2005; NBR 14021:2005; NBR 14022:2005; NBR 14022:2011.

Specific Requirements for Wheelchairs: Below are Brazilian standards that define specific wheelchair dimensions, emphasizing requirements for size, width, height, and other characteristics to ensure compatibility with spaces, including public transport vehicles. Dimensional data impacting projects will be included in their descriptions.

Wheelchairs and Assistive Equipment: NBR 14022:2006; NBR 13962:1997; NBR 14718:2001; NBR 15116:2013; NBR 16259:2013.

Legislation: Brazilian Law for the Inclusion of Persons with Disabilities - Law No. 13,146/2015.

Terminology and Definitions:

- NBR 14023:2000 - Accessibility - Terminology.

Dimensional Restrictions for Wheelchairs: The following restrictions are required to ensure that wheelchairs meet the technical and accessibility requirements necessary for safe and comfortable use in different environments and transportation systems:

- Seat width: 40 cm to 50 cm, depending on the type of wheelchair and user.
- Seat height: Must be adjusted for compatibility with transportation and environments.
- Seat depth: 40 cm to 45 cm to ensure comfort and adequate support.
- Front wheels: Diameter of 15 cm to 20 cm.
- Rear wheels: Diameter of 60 cm to 70 cm.
- Total chair height: Must be appropriate for transportation and accessibility in vehicles and public environments.

Additional Relevant Standards

Other standards impacting design guidelines include transportation-related ones, such as NBR 14022 (2011), addressing accessibility in urban public transport vehicles for collective passengers, as it is representative of general transportation systems. Complementary analyses were conducted for NBR 14020 (2005), NBR 14021 (2005), and NBR 14022 (2005) to identify situations not covered in the public transport standard. The 2018 version replaced NBR 15290 (2018) and was later canceled, so this study did not consider it. The following section presents an analysis of these standards, highlighting elements that impose design constraints and directly or indirectly impact wheelchair development.

In addition to the previously presented standards, the "Technical Dossier for Wheelchairs/BNT-CIT Technical Dossier/20150430," developed by ABNT in 2015, was identified. This dossier comprises various technical standards derived from ISO. These standards address dimensional restrictions on the wheelchair (W.C.) product and establish the necessary tests for its approval. The dossier defines a wheelchair as a "device to provide mobility on wheels with a seat support system for a person with reduced mobility." The standards contained in the dossier detail the specifications and requirements that impact the design and testing of wheelchair prototypes. It is important to note that some of these standards do not yet have translations. Still, the dossier mentions them as recommended references, which can be accessed through the ABNT website.

Only the six topics from ISO 7176 required for obtaining the INMETRO certification will be considered. These topics are:

1. Part 1: Determination of static stability.
2. Part 3: Determination of braking effectiveness.

3. Part 7: Measurement of seat and wheel dimensions.
4. Part 8: Requirements and test methods for static strength, impact, and fatigue.
5. Part 13: Determination of the friction coefficient of test surfaces.
6. Part 22: Adjustment procedures.

However, only the last two parts were not covered in this study:

- Part 13 addresses wheelchair friction on different ground types but does not specify a value for the product, making it more generic.
- Part 22 outlines methods to be used when manufacturers do not provide instructions for making wheelchair adjustments, and it does not directly focus on product dimensions.

Several international and Brazilian standards define the most significant dimensional and testing requirements for wheelchair design. The standards NBR 15250 (2015), NBR 13994 (2007), NBR 14022 (2011), and NBR 15290 (2018) was not considered, as it has been canceled. The remaining applicable regulations comply with NBR 9050 (Brazilian Association of Technical Standards, 2015), establishing accessibility guidelines for urban infrastructure and products and ensuring they meet the needs of individuals with reduced mobility.

Standards Impacting Design

The static stability of wheelchairs, previously covered by ABNT NBR ISO 7176-1:2009 (CANCELED), was updated with ABNT NBR ISO 7176-1:2018, refining test methods for wheelchair recline stability. Similarly, ABNT NBR ISO 7176-8:2009 (CANCELED), which outlined requirements and test methods for static strength, impact resistance, and fatigue durability, was replaced by ABNT NBR ISO 7176-8:2018, reflecting improvements in safety and durability testing.

Meanwhile, ABNT NBR ISO 7176-7:2009 remains valid, providing standardized methods for measuring seat and wheel dimensions, ensuring ergonomic compatibility, and product standardization.

The brake effectiveness test (ABNT NBR ISO 7176-3:2015) assesses braking performance in manual and motorized wheelchairs, with speeds up to 15 km/h, and defines manufacturer disclosure requirements. The friction coefficient test (ABNT NBR ISO 7176-13:2009) evaluates wheel resistance to rotation on rough-textured surfaces like rustic concrete, ensuring traction and stability.

The durability requirements, previously covered by ABNT NBR ISO 7176-15:2009 (CANCELED), outlined information, documentation, and labeling requirements for regulatory compliance. Its cancellation may impact standardized product identification and durability assessments.

Other standards, particularly those related to urban infrastructure and accessible products, follow the guidelines of ABNT NBR 9050 (2015), which is referenced at the beginning of each regulation. These technical standards, including those specific to wheelchair design, provide the necessary parameters for product development and evaluation, ensuring

accessibility and safety for users. The NBR 9050 standard establishes minimum manoeuvring space requirements for manual and motorized wheelchairs to ensure accessibility. The required dimensions for wheelchair rotation are 1.20 m × 1.20 m for a 90° turn, 1.50 m × 1.20 m for a 180° turn, and a 1.50 m diameter clearance for a 360° rotation. These guidelines ensure wheelchair users have sufficient space to move comfortably and safely in various environments.

By following current standards, manufacturers can ensure that wheelchairs meet essential safety, comfort, and performance requirements. These regulations help design accessible products and environments, addressing the needs of individuals with reduced mobility while promoting social inclusion in various spaces and transportation systems.

The established standards define the mandatory design constraints and testing requirements necessary for INMETRO approval, ensuring compliance with quality, safety, and functionality criteria. This guarantees that wheelchairs meet accessibility standards and user needs.

For access to the ABNT technical standards referenced in this article, the ABNT Catalog website was the only source consulted, providing complete documentation.

Guideline for Wheelchair Design Considering Standards, Costs, and Aesthetics

The product development process (PDP) involves product design, manufacturing planning, and production to deliver the final product. Among these three stages, according to Pahl et al. (2005), the product design phases consist of four phases: Task Clarification, Conceptual Design, Preliminary Design, and Detailed Design. The first phase is fundamental for defining the technical characteristics to be incorporated into the product, referred to as "technical design requirements". The phases are:

- **Task Clarification:** Survey of the state of the art; Identification of customer needs; Prioritization of technical requirements for customers. **Outcome:** A detailed list of technical design requirements.
- **Conceptual Design:** Define the product's function structure; Develop function concepts and a final product design according to customer needs.
- **Preliminary Design:** Detailed conceptual solution into feasible technical configurations; Definition of the product's physical structure; Selection of materials and manufacturing processes; Creation of graphical representations and prototypes; Execution of preliminary technical analyses; Preparation of essential documentation.
- **Detailed Design:** Preparation of technical drawings; Specification of materials and tolerances; Definition of manufacturing processes; Assembly and testing procedures.

Based on the sequence proposed by Pahl et al. (2005), the first two phases involve Task Clarification and Conceptual Design. In the Task Clarification phase, the designer must outline the project guidelines so that the outcome

is oriented toward the essential solution to the problem. During this phase, questions such as "What is the problem?" and "What implicit desires and expectations are involved?" should be addressed. Both answers must consider what wheelchair users expect from the product, access to environments, and social inclusion. This phase should include:

- A survey of the state of the art for similar products to understand the technical characteristics of available products and competitor pricing.
- Identification of the needs of potential customers and the numerous design constraints or recommendations.
- Consideration of attractiveness and low cost to make the product accessible to everyone.
- Listing technical characteristics to incorporate customer needs into the product.

A state-of-the-art survey and analysis of similar products in national and international markets are conducted during the Task Clarification or Informational Design phase. The findings reveal a scarcity of playful, colorful, and humanized wheelchair designs. Among the few identified, the "Ipanema amphibious beach wheelchair" is priced at USD 647.40, while the "Lunna Wheelchair" costs USD 4,380.00. Additionally, an international search using "playful/attractive wheelchair" yielded no appealing results, suggesting a promising market opportunity.

Searching for "wheelchairs" reveals that low-cost models tend to be fragile, simple, and uncomfortable, adhering to traditional designs. In contrast, higher-cost wheelchairs are more robust and feature-rich but maintain a conventional aesthetic. According to Lima et al. (2016), wheelchair prices in Brazil ranged from USD 86.00 to USD 8,257.00, while in 2024, prices varied between USD 103.00 and USD 4,300.00. This demonstrates the significant price gap between basic and premium models, reflecting differences in quality, durability, and additional functionalities.

Although wheelchairs are available in the Brazilian market for as low as USD 103.00, considering the minimum wage in Brazil (USD 218.00 in 2024), the cost of a basic wheelchair represents approximately half of a minimum monthly salary. Furthermore, 60.1% of the population lives on up to one minimum wage per month (Valor Investe, 2022), reinforcing the urgent need for more affordable solutions. Customer needs are classified as mandatory (regulatory for INMETRO approval), priority (customer preferences), desirable, and sales-boosting. These needs are translated into technical requirements during the design process. Mandatory requirements are incorporated in the second conceptual design phase, while priority ones must be met without exceeding competitor prices observed in the state-of-the-art survey. Desirable features address unmet consumer demands at low costs, and playful design elements help reduce invisible barriers. The QFD (Quality Function Deployment) method prioritizes customer needs, particularly the First House of Quality (Akao, 1990), while regulatory requirements remain

separate to ensure product approval. This phase concludes with a meta-specification listing all requirements, standards, and production control metrics.

The Conceptual Design phase begins with defining the Function Structure, breaking the global function into sub-functions to generate solution ideas. The Morphological Matrix expands possibilities by cross-referencing problem components with solutions, fostering creativity. Generated solutions are compared with customer preferences using the Pugh Matrix (Pugh, 1991), which ranks options based on sales potential and acceptability. This ranking can be combined with the QFD First House of Quality for technical prioritization. Research by Carla Estorilio (2017), based on 20 years of engineering project tests, shows that the winning design remains consistent in both Pugh Matrix applications (customer needs vs. technical requirements). However, the technical ranking produces a more distinct winner, scoring differences of 100 points or more, compared to 1 to 10 points in the customer-needs version. The highest-scoring design moves forward to the Preliminary and Detailed Design phases for manufacturing and commercialization.

CONCLUSION

The study presented a project guideline encompassing standards and recommendations for developing a wheelchair, including the minimum requirements necessary for approval by INMETRO. In this context, the requirements are classified as mandatory, while others are considered essential to make the product more attractive and competitive. The article highlighted the seven principles of Universal Design: equitable use, flexible use, simple and intuitive use, perceptible information, tolerance for error, low physical effort, and appropriate dimensions and space for approach and use. Subsequently, accessibility standards were analyzed, focusing on those that impact wheelchair design with guidelines for accessibility and safety. Moreover, the "Technical Dossier for Wheelchairs/BNT-CIT Technical Dossier/20150430," prepared by ABNT in 2015, was identified. It contains standards derived from ISO. The standards included in the dossier impact both the design and testing of wheelchair prototypes; however, only six topics from ISO 7176 are required for INMETRO certification. These standards address static stability, braking effectiveness, seat and wheel dimension measurements, and static strength, impact, and fatigue requirements. The study detailed four items from ISO 7176 that impact development: 1 – Determination of static stability; 3 – Determination of braking effectiveness; 7 – Measurement of seat and wheel dimensions; and 8 – Requirements and test methods for static strength, impact, and fatigue.

Finally, the study presents the design methodology for conducting the "Task Clarification" and "Conceptual Design" phases, emphasizing the moments when standards and requirements should be considered and including technical details to make the product attractive and low-cost. During the state-of-the-art survey of similar commercial products, a lack of products with appealing designs, affordable prices, and compliance with INMETRO standards was observed. It is suggested that future work focuses

on developing attractive, low-cost prototypes that more effectively meet INMETRO requirements.

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