Proaid E. Low Cost Neurological Wheelchair Design

Gustavo Sevilla Cadavid, Andres Valencia-Escobar
and Juliana Velásquez Gómez

Abstract Low-income disabled people in Colombia routinely face problems in accessing reasonably priced assistive devices and disability products. The standard, low-cost Proaid M wheelchair, made with assembled laminated wood components and commercially available materials, is an object-based response to this problem. Based on the Proaid M design, a new model—the Proaid E—was developed for a 12-year old child with mixed cerebral palsy. The project combined the analytical systemic model "Disabled People-Built Environment" with a focus on user-centered design. The end result of this project brought about a marked improvement in the quality of life of an individual who had previously been denied the minimum necessary conditions for basic mobility.

Keywords Disability · Industrial design · Assistive devices · Ergonomics

1 Introduction

The design of assistive devices [1] is a response to those needs that emanate from an individual's limitations when interacting with the environment. This is achieved through the development of products that act as mediators between an individual's physical and cognitive characteristics and the functional characteristics of the environment. These products can dramatically improve the quality of life of disabled people, as well as older adults, people who suffer from obesity, those of small stature, and many others.

G.S. Cadavid (✉) · A. Valencia-Escobar
Universidad Pontificia Bolivariana, Medellín, Colombia
e-mail: gustavo.sevilla@upb.edu.co

A. Valencia-Escobar
e-mail: andres.valencia@upb.edu.co

J.V. Gómez
Escuela de Ingenieria de Antioquia—Universidad CES, Medellín, Colombia
e-mail: juliana.velasquez@eia.edu.co

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Assistive devices should achieve their objective of preventing, redressing, controlling, mitigating and neutralizing an individual's deficiencies, activity limitations and participation restrictions. Their design must therefore take into account the anatomical, biomechanical, anthropocentric, cognitive and social characteristics of those individuals that become direct users of such devices. Universal Design, Inclusive Design, ergonomics and usability are some of the approaches that help to create products with high levels of functional adaptation based on physical, cognitive and socio-economic characteristics.

That last characteristic is important if one considers that many disabled people living in developing countries have to deal with challenging social and economic conditions, a situation compounded by limited access to assistive devices [2]. Under the current health system in Colombia, disabled people have access to a limited number of assistive devices and disability products. However, not all product groups established by the ISO 9999 standard are available or supplied through Colombia's Compulsory Health Plan [3]. This means that assistive devices, which are relatively expensive in Colombia, are unobtainable for a large majority of end-users, many of whom live in poverty [4].

It is at this point that concepts such as universal design, ergonomics and usability begin to play a key role in the development of assistive devices that meet a practical function, and that are adaptable to social and economic conditions, making them easier to acquire. Taking into account the difficulty that low-income disabled people have in accessing assistive devices, organizations such as the American Wheelchair Mission, the Free Wheelchair Mission and the Wheelchair Foundation, and individuals such as Doctor David Werner, have promoted local initiatives to produce assistive devices in developing countries, all of which have focused on the development of low-cost products.

This can refer to low-cost objects; objects that can be manufactured using low-cost tools; or objects that are cheaper than commercially available products and which carry the possibility of being made in a home environment. The Design Study Research Group (GED) at the Universidad Pontificia Bolivarianás Industrial Design Faculty in Medellín (Colombia) has been working since 2008 on the design of low-cost products that meet not only the physical needs of disabled people, but also take into account their financial situation.

The first product to be developed was the Proaid A—a wheelchair manufactured from PVC tubing (Fig. 1) that sought to meet the requirements mentioned above. The project also explored opportunities for the product to be homemade and/or manufactured on a local scale [5]. After addressing a number of issues in the Proaid A, work was then carried out on the design of a second wheelchair—the Proaid M (Fig. 2). This new model comprises five basic plywood pieces that are assembled to form a base structure. The wood pieces are joined together using a special slot system, rather than adhesives or mechanical fasteners. Front and rear wheels and brakes are then attached to this base structure. Commercial wheels may be used, or alternatively they can be built from two plywood sheets with circular

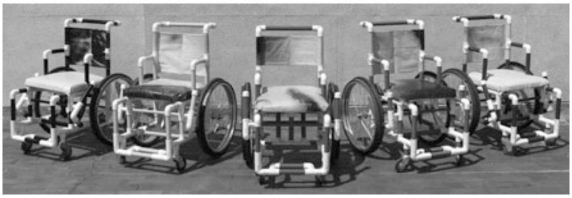

Fig. 1 Proaid a wheelchair. GED archive

Fig. 2 Proaid M wheelchair. 3D model. GED archive

perimeter. The sheets that are used to build the backrest, the seat and the footrest can be perforated to reduce the weight of the structure and improve air circulation.

The Proaid M wheelchair design—whose versatility can be seen through the use of low-tech tools and low-cost materials during the manufacturing stage—makes it possible for different adaptations to be developed to meet the specific needs of the user. To validate the level of adaptation to users with particular needs, a decision was taken to design a neurological wheelchair model for an individual suffering from cerebral palsy. The model was named the Proaid E. This project posed a challenge for the design team given the physiological, anatomical, cognitive, biomechanical, anthropometric and sociocultural complexities related to the user. The team also had to contend with the limited amount of available information concerning neurological wheelchairs, the medical nature of information, the high costs involved for this type of product and problems related to Colombian health system's supply model [6].

This project aims to highlight the importance of developing low-cost assistive devices for disabled people, and the benefits that these devices can generate. The project also underlines the value of interdisciplinary development teams, which in this case has comprised industrial designers, mechanical engineers, biomedical engineers and industrial design students at the Universidad Pontificia Bolivarianás Industrial Design Faculty. This led to the development of a neurological wheelchair that responds to functional, operational, technical-productive and aesthetic-communicative demands, and which is adaptable to local economic conditions.

2 Methodology

The Proaid E's design process followed a methodology adopted by the GED following their experience in research and product development. The process was based on user-centered design, the analytical systemic model "Disabled People-Built Environment" [7], and the methodology used during the Escuela de Ingenieria de Antioquia and the CES University's development of shaped seating. The different stages of the applied methodology were as follows:

- Information: In this stage, the user is observed in an active state in order to collect information about their psychophysical, sociocultural and technological requirements (requirements, characteristics, limitations, restrictions, criteria). The properties that are determined in this stage relate to the tensions between the user's characteristics, the object (the wheelchair) and the context i.e. problems that have to be resolved. An understanding of the user and the dynamics of the context provide information that can be introduced into the design process. A problem is then defined in terms of requirements and specifications.
- Formalization: In this stage, the form becomes tangible through models and prototypes, which are proposed for each of the tensions that make up the psychophysical, sociocultural and technological needs of the user and context, and which neutralize the problem in terms of functional, communicative and morphological dimensions. The objective of this phase is to convert the information acquired in the previous stage into a more formal proposal i.e. a solution to the problem.
- Conformation: This is the last stage of the design process, when the wheelchair that has been designed during the formalization process is introduced to the context, either as a product or service. A materialization process generates and adds a series of values to the proposed object, which provide it with meaning—be it commercial, institutional or cultural—and allows the user to recognize in this final form a solution to the original problem. It is the moment in which the wheelchair is introduced to the context and acquires a practical sense by the end-users.

3 Results

3.1 Information Stage

As part of the information stage—and within the context of establishing the user's characteristics—an analysis of human factors was carried out that determined that the user of the neurological wheelchair was a 14-year old adolescent with athetoid cerebral palsy contracted during the prenatal stage as a consequence of twinning problems. The user was quadriplegic due to problems in the upper and lower limbs, and suffered from serious functional impairment (Fig. 3).

Fig. 3 Project user. GED archive

The user's most characteristic feature is altered neuromotor function, demonstrated by an increase in muscle tone, the inability to maintain postural control and sudden changes in movement patterns. There are also issues related to visual perception and the proprioceptive mechanism, spatial awareness in relation to objects, altered body schema, altered language and communication skills caused by damage to cerebral areas and an increase in muscle tone in the nasal, oral, and pharyngeal area. Finally, the user suffers from epilepsy and intellectual developmental disorders as a result of neurologic injury.

The user cannot walk unaided and suffers from a complete lack of balance and handling ability. The user also suffers from joint disorders and problems in the torso caused by structural scoliosis. This is a person dependent on each and every one of their needs. It is difficult to source anthropocentric tables for the subsequent sizing of the wheelchair, as the user's weight and size is below average for their age and gender (masculine).

During the product characterization process, an analysis into the current state of the neurological wheelchair market was carried out. The results show that assistive device design has led to the development of many wheelchairs that have been adapted for users with neurological disorders. However, it was discovered that these chairs are five times more expensive than conventional wheelchairs. These products are equipped with a series of adaptations that allow the user to move around safely and comfortably. Most of these adaptations cover basic requirements and meet the comfort needs of patients, and in particular children.

A review of existing wheelchairs shows that the majority appear to have three subsystems: (1) Chest and abdomen support; (2) Upper and lower limb support; and (3) Head support. Most feature detachable and adjustable armrests at user height, and have two detachable footrests with a height adjustment option to match the user's anthropocentric dimensions. They also include padded and detachable head support, lower back support and a fastening system using straps.

A characterization of the context showed that in terms of urban accessibility, steps close to the entrance of the user's home were inadequate for wheelchair use, either because they lacked private paving or because they were poorly built and

Fig. 4 Companion and user dealing with restricted movement. GED archive

were more than 3 cm high. There were no wheelchair access ramps in the surrounding four blocks of the user's home, while the nearby sidewalk surfaces were irregular and in poor condition, which impeded mobility.

In terms of architectural accessibility, the main problem for the user and the carers were stairs. The user's bedroom is located on the second floor, meaning access to the area is difficult, while assistance from two people is always required. The small spaces limit mobility for the user and the carer (Fig. 4). Doors are another major obstacle, especially for wheelchair users. This problem is difficult to resolve because of the minimum dimensions laid out by architectural rules, and the fact that the direction in which the doors open is not indicated. The bathrooms are unable to provide safe and optimal access for the user as the sink and toilet are too high and there is a lack of space to access them from a wheelchair.

During the activity analysis, only one action was selected on the basis that it was the most difficult to carry out. According to the carers, accessing the bathroom was identified as one of the most dangerous basic activities due to the risk of falls and injuries caused by the user's functional limitations, their weight and inadequate space and objects. The carers occasionally lost their balance while carrying the user due to the lack of support systems in the bathroom that the carer could grip. This created insecurity and increased the risk of falls. The shower was also a risk factor due to a poor water runoff system that also increased the risk of falls. This carer subsequently chose to wash the user in bed, which created further complications.

3.2 *Formalization Stage*

The key concept was adaptation. This was explained in terms of "adaptive mobility", a basic concept of the previous Proaid models. Based on this premise, the project can be properly adapted to the needs and mobility issues of low-income disabled people. Another conceptual factor that was taken into account was the possibility for the wheelchair to be made in the home environment. This would represent a shift in current thinking that wheelchair users cannot be part of the manufacturing process. The process also sought to adhere to the directives of the World Health Organization

[8], which state that all projects of this kind should take into account the product's entire lifecycle, including an analysis of the user, their training from the moment they receive their wheel and production and maintenance of the wheelchair.

Once the conceptualization of the product had been established, a next stage examined the design of alternatives. This activity in the design process results in a set of solutions to the problem, with a degree of descriptive definition. An experimental search method based on Ritchey's Morphological analysis was used [9]. Computerized models using Solid Edge software were then created, while structural analysis of resistance, rigidity and stability was carried out according to the model put forward by the GED's experimental morphology research group [10]. At the same time, the minimum ergonomic conditions to guarantee comfort and safety were defined. This process allowed the form to evolve, from initial ideas to the final model.

3.3 Conformation Stage

The final design requirements were determined from ergonomic factors (biomechanics, anatomical anthropometry, socio-economic) and object-based factors (form, function, materials, structures, color, etc.), and tested to see which possessed the most formal, functional and productive feasibility. Because the user suffers from asymmetrical posture and spinal deformation caused by scoliosis, the wheelchair's design should address the space created when the user's back comes into contact with the support area. To resolve this issue, the Biomechanics Laboratory at the Escuela de Ingenieria de Antioquia and CES University helped to develop shaped seating [11].

The shaped seating is a support surface made from polyurethane—26 density and 50 mm thickness—that matches the user's anatomical shape and allows a close fit between the user and the seat. This type of seating helps prevent the formation of pressure ulcers in adults and helps children to maintain good posture while offering comfort and support (Fig. 5a–c).

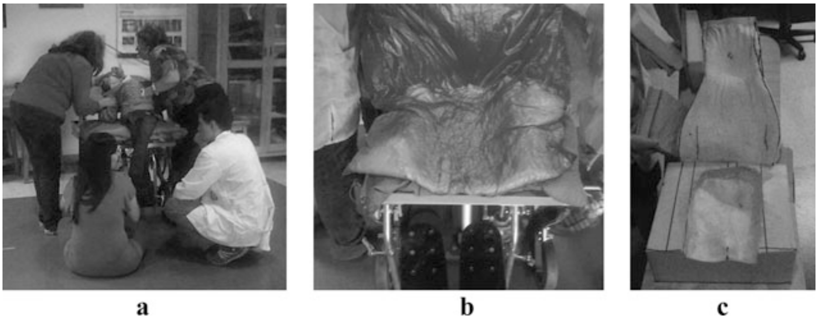

Fig. 5 **a** Taking a mold of the user's spinal column, back and pelvis. **b** Fabrication of the counter-mold of the user's spinal column and pelvis. **c** Shaped seating

The best postural position for the user was achieved when the front part of the seat was tilted backwards at an angle of 5°, creating an angle of 145° between the user's back and the seat. A pelvic belt should be attached to avoid slipping and to help create optimal posture. In addition, support should be added on the right side of the user's abdomen, as the user tends to strain when uncomfortable, which increases spinal curvature related to scoliosis. To compensate the user's inability to maintain postural control of the neck and head, the wheelchair must be fitted with head restraints at the sides.

In order to create an efficient drive system, it was decided that the wheelchair's rear wheels should be bigger than the front jockey wheels. Standard bicycle wheels with a 16″ diameter and a 1.5″ thickness were fitted, with aluminum rims to reduce weight, tires for shock absorption and steel blocks for lateral support. The commercially available jockey wheels were 5″ in diameter and located at the front of the wheelchair, and finished with a polyurethane coating finish—ideal for indoor areas and hard and smooth ground surfaces. For the drive system, a standard MTB bicycle handlebar was chosen as it provided grip and enough mechanical advantage to allow interaction with the wheelchair. A special piece of equipment was designed that joined the wooden structure with the stem and handlebars. A standard break pad system was selected and attached to the structure by a mechanical fastening system. The central structure of the wheelchair keeps the same slot-based assembly system used for the Proaid M, which is made from laminar pieces of plywood and proved to be efficient and safe (Fig. 6). However, the edges of the pieces were adjusted to adapt the ergonomic variables to the wheelchair user.

For the formal and functional physical modeling, a number of prototypes using 18 mm-thick plywood sheets were assembled (Fig. 7a). Each prototype underwent systematic and sequential physical, mechanical and production testing (Fig. 7b), which yielded information for formalization that was then fed back into the process. All prototypes were made using technology that a user could be expected to utilize in a home environment. The structural tests for each of the prototypes were carried out according to the test protocols of the regulation ISO 7176-1 [12], and through Whirlwind International's proposed model, which conforms to the guidelines of the ISO standard, but is executed with the help of simple tools and materials [13] (see Fig. 8).

Fig. 6 Slot-type connection

a b

Fig. 7 **a** Pieces of plywood sheeting for a prototype. **b** Prototype ready for testing

Fig. 8 Lateral static resistance test of the structure

Fig. 9 Dimensional and anatomical fitting test of shaped seating. GED archive

Usability tests were carried out using the GED Ergonomics Research Group's product valuation proposal [14]. Anthropometric and anatomical fitting tests were carried out (Fig. 9), while comfort levels from a perceptive standpoint were evaluated with input from support workers (physiotherapists, bioengineers, physiatrists) and the user's carers. The carers helped to identify different aspects of the product

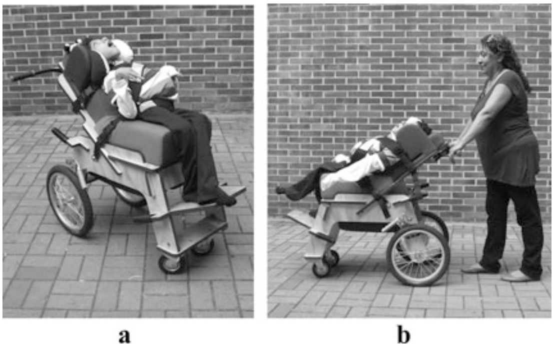

Fig. 10 **a** User with final prototype. **b** Individual pushing the Proaid E neurological wheelchair

that needed to be improved, which led to modifications being made to better suit the user's particular needs. This was done according to the guidelines of user-centered design and participatory design.

During the detailed design and final production process, a prototype was developed and given to the user's family (Fig. 10a, b). The project also identified how the wheelchair could be mass-produced using numerical controlled machinery. This would reduce production costs if the project were expanded.

4 Conclusions

The most significant conclusion to be drawn from this project is that through a concurrent and user-centered design process, it is possible to meet the specific needs of disabled people with object-based solutions. These can be adapted to meet not just technical and medical requirements, but also the group's aesthetic and economic needs. The design of support products like the Proaid E is therefore an exciting challenge, albeit one that is full of uncertainty and challenges from a technical, financial and business standpoint. However, the designer's voice must be heard for the benefit of disabled people.

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