Ingeniería e Industria	Diseño ergonómico de un andador robótico inteligente basado en la percepción y necesidades de los usuarios. Ergonomic Design of an intelligent robotic walker based on user perception and needs	UNESCO DYNA 5311.99-8
RESEARCH ARTICLE	Isabel Seguí Verdú, Larisa Dunai, Valeriy Vyankin, Dinu Turcanu	PRODUCT/SERVICE DESIGN AND DEVELOPMENT

ERGONOMIC DESIGN OF AN INTELLIGENT ROBOTIC WALKER BASED ON USER PERCEPTION AND NEEDS

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ABSTRACT*:*

This article presents the development of a robotic walker designed from an ergonomic perspective, focused on users' specific needs. The design integrates a height-adjustable modular system, a rectangular frame with four wheels to ensure stability and manoeuvrability, and a vertical folding mechanism for easy transport.

Key components were optimised: ergonomic handles with support and grooves for improved grip, an anatomical seat made of memory materials, a durable fabric backrest, and a sports bag-type basket attached by hooks. The 24 mm front wheels are spring-loaded to reduce vibrations, while the 20 mm motorised rear wheels have a non-slip surface for overcoming obstacles.

The design incorporates safety features such as reflective strips, integrated lights, and advanced sensors (pressure, TOF, IMU), enhancing user comfort, functionality, and safety. This comprehensive approach represents a significant advance in the ergonomics and functionality of robotic walkers.

Key Words: robotic walker, ergonomic design, user-centred design, handgrips, frame, seat, wheels, electronics, sensors

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1. INTRODUCTION

Population growth and advances in health have increased life expectancy. According to the World Health Organization (WHO), by 2050, the world population over 60 will be 3.5 billion, almost double that of 2020 [1]. In addition, those over 80 years of age will triple, especially in Japan and Europe [1].

The development of assistive technologies is aligned with the Sustainable Development Goals (SDGs), promoting innovative solutions to improve the quality of life of the elderly [2].

As defined by the WHO, assistive technology encompasses products and services that facilitate mobility and autonomy. An estimated 2.5 billion people require at least one assistive product. In response, WHO developed the Assistive Products Priority List (APL), which includes 50 essential devices such as walkers, rollators, and canes to ensure mobility, independence, and overall well-being [3].

Walkers are key tools in assisted mobility, offering more excellent stability than canes and more autonomy than wheelchairs. Walkers are divided into three main categories: wheelless, rollators and robotic. Walkers without wheels are the most stable but require lifting with each step, which generates fatigue. Rollators incorporate wheels and brakes, improving mobility, although they can be unstable. Robotic walkers integrate sensors to enhance safety, but their ergonomics remain challenging.

Robotic walkers can offer passive or active support depending on their design:

- Passive: assists movement without motorised intervention, adapting to the user's requirements through force sensors and algorithms that optimise gait and reduce physical load. Technologies such as omnidirectional platforms and linear motors improve mobility and body support.
- active: Provides motorised assistance through actuators, ideal for severe disabilities. It uses advanced control systems that process sensor data to optimise performance.

According to medical professionals, the ergonomic design prioritises comfort and safety, focusing on user training rather than automation [4].
Through surveys and interviews with end users and medical staff, four key needs were identified: mobility, safety, accessibility, and autonomy.
The main objective of the study is the development of an intelligent robotic walker that addresses these needs, incorporating advanced ergonomic and technological features. The design prioritises stability, effort reduction and personalised fit to optimise safety, functionality, and comfort.

In assisted mobility, ergonomic design prevents injury and improves comfort [5]-[8]. Handles are a critical point of interaction, and their customisation in shape, material and adjustability reduces strain on wrists and arms, especially in people with reduced strength or joint problems [9]. Non-slip, lightweight handles improve safety and reduce fatigue.

On the other hand, the adjustable height of the walkers reduces shoulder and back strain by allowing comfortable bending of the elbows, which is essential for older users who may experience discomfort or instability with ill-fitting devices. Features such as non-slip wheels, wide bases and balanced weight distribution improve stability and reduce the risk of falls, according to anthropometric studies on the diversity of heights and physical abilities in the elderly population.

User-centred design ensures that the walker addresses functional and physical needs, from post-surgical recovery to chronic problems. However, many current walkers prioritise only functionality without considering the user experience or the needs of caregivers.

Several projects have integrated active support into their designs [10]. For example, ASAS and SIMBIOSIS employ platforms on the forearms to provide stability and assistance [11]. HealthWalk [12] uses sensors to improve posture and prevent falls, while a longitudinal case study highlights the importance of autonomous upright mobility using a motorised device. On the other hand, [13] discusses intake controllers that adjust speed according to the force applied by the user, with the potential to improve active support. Systems such as those described in [14], which integrate gait training with walker technology, stand out as innovative solutions.

The continuous improvement of passive support in robotic walkers seeks to offer devices that promote a more active and independent life. Studies such as [15] and [16] highlight the importance of incorporating ergonomic design and innovative technologies in these devices.

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Most smart walkers use rectilinear frames, as in the ASBGo++, i-walker and Jarow [17] models, for their stability and optimal weight distribution. However, some designs explore innovative shapes, such as circular or U-shaped frames, present in AGORA, CAIRO, COOL Aide, GUIDO [18], i-go, ISR walker, Jaist [16], PAMM [19], Panasonic, MOBOT, Sprint, UFES, Symbiosis [20], XR4000 and ZJU walker. Despite these variations, rectangular frames are still preferred due to their biomechanics and stability, such as the ASBGo++, which is explicitly designed for people with ataxia.

Advanced technologies, such as intelligent sensors to detect obstacles or uneven surfaces, improve safety and ease of use, addressing key user needs such as autonomy in daily activities, stability on uneven surfaces, and reducing fatigue in the elderly. In addition, these technologies optimise mobility, safety, and accessibility.

The Materials and Methods section describes the surveys and methods used to define the walker's design, including questionnaires, interviews, and direct observation. Comfort, usability, stability, adaptability, and ergonomics were evaluated and selected according to surveys and interviews, where users emphasised the importance of reducing walking effort, maintaining proper posture, and facilitating use in different environments. Results show user preferences for grip, height, stability, and walking effort, as well as problems such as joint pain and balance difficulties, which guided the selection of materials and functionalities.

The data highlight the importance of adjusting dimensions and materials to optimise comfort and stability. The study proposes a framework for accessible, functional, and sustainable devices aligned with the SDGs.

2. MATERIALS AND METHODS

2.1 STUDY WITH USERS ON THE DESIGN OF THE WALKER

This study is based on several analyses of user preference for the robotic walker and its mechanical components.

For the user study, 12 semi-structured face-to-face interviews and a survey were conducted with 56 participants aged 60 to 85, administered online and face-to-face. The interviewees were grouped into three profiles: health professionals (4), caregivers (4), and end users (4), selected for their experience with walkers and their ability to provide relevant information. Health professionals have more than five years of experience in rehabilitation and assisted mobility. Caregivers included formal assistants with training in elderly care and family members without specific training but with experience caring for people with reduced mobility.

The survey included people with distinct levels of dependency: 60% mild or moderate and 40% high. The questionnaire combined closed multiple-choice and open-ended questions to capture subjective perceptions. Two independent physiotherapists and two engineers performed its validation through expert judgment, ensuring the items' clarity, relevance, and appropriateness for the target population.

The 18-question questionnaire addressed key aspects of walker use, including user profile (age, gender, level of dependency, time of use), purchase experience, rating of the walker (comfort, ease, etc.), preferences and improvements (handles, adjustments, etc.) and perceptions of motorisation (weight, safety, etc.).

The interviews provided detailed information on interaction with the walkers and perceptions of their functionality. The survey complemented these findings by expanding the preferences in walkers to include:

- Curb and slope assistance systems.
- Motorized system.
- Comfort and ergonomics.
- Cost and accessibility.

To define the design of the robotic walker, key mechanical components were discussed with respondents:

- Structure and materials.
- Wheels and materials.
- Handles: Shape and materials.
- Brakes: Passive and automatic.

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- Seat: Rigid, fabric or rigid with foam.
- Backrest: Cylindrical with rubber or flexible padded.
- Basket: Metal or sports bag type.
- Safety: Reflective tapes and integrated lights to improve visibility.

Qualitative data were analysed using a thematic approach, and quantitative data was gathered using descriptive statistics, providing a solid basis for technical and ergonomic analysis. The study highlights the importance of integrating the needs of users, caregivers, and professionals in the design of assistive devices, prioritising functionality, safety, and comfort.

2.2 WALKER DESIGN CONSIDERATIONS AND COMPONENTS

Despite technological advances, smart walkers prioritise safe and practical assistance but face key challenges:

- Cost: Their advanced technology makes them more expensive than conventional ones. Conventional walkers cost between €70 and €600, while commercial robotics range from €1,960 (IROLLER [21]) to €4,029.90 (Rehabilitation Robot [22]), with intermediate options such as RT2 (€3019.33) and “Intelligent 2-in-1 Assistant Robot” costing €3,591.76 [23].
- Complexity: they incorporate motorised wheels, force sensors, Time of Flight (TOF) sensors and batteries, increasing the difficulty of use and maintenance.
- Weight and size: despite using lightweight materials, smart walkers are still heavy and bulky, which generates reluctance in users [24]. Conventional walkers weigh from 7.5 kg to 10 kg, while robotic walkers range from 9.3 kg (RT2), 19 kg (IROLER), 47 kg (Intelligent 2-in-1 Assistant Robot) and up to 82 kg for the Rehabilitation Robot [22]).
- Maintenance: its electronic and mechanical components require periodic servicing.
- Reduction of physical effort: Excessive use of assisted functions can reduce muscle strength.
- Safety: Technological failures may represent risks for fragile users [25].
- Accessibility: Availability may be limited by cost or regional factors.

It is critical to balance the functional benefits of smart walkers with practical factors such as weight, cost, and user acceptance.

Intelligent or robotic walkers improve mobility and support by integrating technology. Depending on their design and functionality, they are classified into three main types:

- Standard structure with integrated technology: Based on the traditional four-legged frame, they add sensors, motors, and control systems [11]. Their cost-effective design facilitates the transition from conventional rollators.
- Intelligent rollators: Equipped with wheels and brakes, they improve stability and manoeuvrability by incorporating advanced technology [12].
- Integration with exoskeletons: They provide motorised assistance in legs and hips, benefiting people with Parkinson's disease or paraplegia [26].

The walker developed in this study is based on a rollator-type model based on ergonomic criteria and surveys of users and caregivers. Its design promotes mobility, independence, and safety.

- **Frame or structure:** The primary support of the walker is made of light and durable materials such as aluminium or carbon fibre.
  - Alternative designs: Circular models, while innovative, are costly and uncomfortable, as they make alignment with the centre of gravity difficult. U-shaped designs (UFES, i-GO, JAIST) improve ergonomics but sacrifice stability.
  - Rectangular structure: Previous studies confirm that it offers the greatest stability and functionality, so it was chosen as the basis for the device (Figure 1).

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a) b)

Figure 1 3D model of a walker: a) classic rectangular, b) ergonomic with forearm support.

- **Wheels:** Intelligent rollators equipped with wheels offer greater mobility than traditional rollators. Depending on the design, the wheels can be static, beaver-type, Swiss or spherical (Figure 2). Omnidirectional wheels, such as beaver-type wheels, stand out for their manoeuvrability, as shown by studies [27].

  Combining beaver-type front and fixed rear wheels optimises stability and manoeuvrability on uneven terrain. In addition, the size of the wheels is critical:

  - **Larger diameter:** facilitates overcoming obstacles and improves user comfort.
  - **Tire material:** Key to stability and durability. Walkers usually use solid rubber or plastic wheels.

a) b) c) d)

Figure 2 Types of wheels used in walkers, rollators, and robotic walkers. a) static, b) castor, c) swiss, d) spherical.

- **Handgrips:** Essential for a safe and comfortable grip, they facilitate the control of the walker and the user's balance (Figure 3).

a)	b)	c)	d)	e)	f)

Figure 3 Types of handgrips on walkers. a) Cylindrical with self-made support. b) Cylindrical with thumb protrusion and lower grooves for self-made fingers. c) Cylindrical with rubber grooves. d) Cylindrical with a porous surface adapted to the hand and fingers. e) Ergonomic rubber with grooves for fingers f) Manual brake for walkers.

Some models of smart walkers integrate sensors in the handles to detect the user's intention and adjust the level of assistance. Passive walkers have various handles, from cylindrical foam handles to cylindrical rubber handles with grooves to contoured handles and/or thumb support.

- **Brakes:** Essential for safety, they allow the walker to be stopped efficiently and controlled. In smart models, they can integrate advanced technology with automatic activation according to the user's needs or the environment (Figure 3-f).
- **Seat:** Its design should prioritise comfort and adequate support (Figures 4-a and 4-b). However, this aspect is often underestimated in robotic walkers, who use fabric seats or designs without ergonomic considerations and satisfy only functional requirements.

Figure 4 Seat models: a) rigid, b) flexible fabric; Backrest models: c) rigid, d) flexible padded fabric; Walker basket: e) rigid metal, f) sports bag.

- **Backrest:** Designed in resistant fabric, it provides adequate support to the user's back, combining comfort and durability. Its design allows efficient vertical folding, facilitating storage and transport (Figure 4-c and 4-d).
- **Basket:** Conventional walkers include a rigid metal and sports bag-type basket (Figures 4-e and 4-f). The metal basket under the seat predominates in the Mediterranean area due to its strength and safety, but experimental robotic walkers usually lack storage.

3. RESULTS

3.1. SURVEY RESULTS ON ROBOTIC WALKERS

The study began with qualitative interviews to identify key needs and guide the design of surveys on robotic and non-motorized walkers with a user-centred approach.

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The analysis of 56 surveys made it possible to adapt the design to actual demands, optimising ergonomics, ease of use, efficiency, and portability. Of the respondents, 51.8% were over 80 years old, 26.8% were between 71 and 80 years old, 10.7% were between 60 and 70 years old, and 10.7% were under 60. Regarding gender, 76.8% were female, and 23.2% were male.

Figure 5 shows the users' interest in curb and slope climbing aids, which were rated positively by 50% of the respondents, although some expressed concerns about weight, battery, and safety. Some 25% were unsure, and another 25% showed no interest (Figure 5).

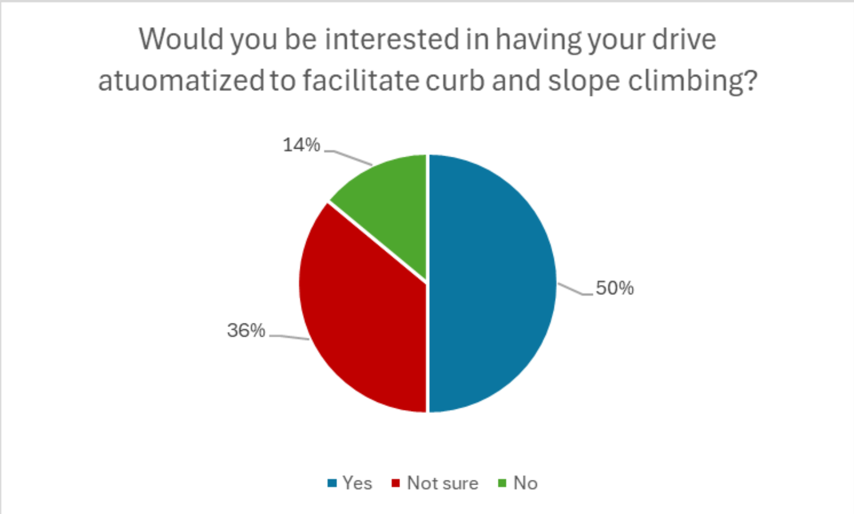

Figure 5 Opinions on walker automation for overcoming obstacles.

The incorporation of motorised systems generated concerns (Figure 6) due to increased weight (80% of respondents), battery life (62.5%), and maintenance and repair costs (75%).

Motor safety is a concern of 53.6% of respondents, highlighting the importance of reliable brakes and control. Affordability and minimal maintenance were also essential, as additional costs and complexity could limit accessibility (Figure 6).

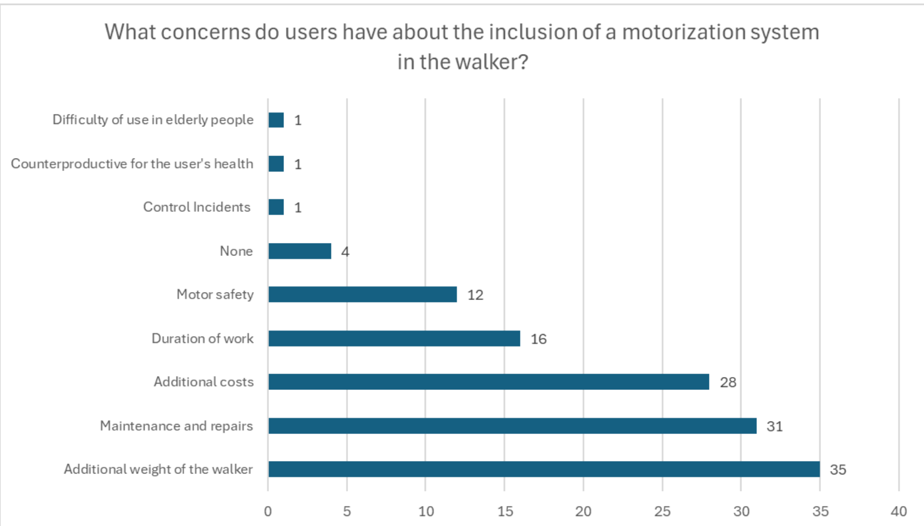

Figure 6 User Concerns

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In addition to motor safety, users expressed concerns about other aspects of motorised walker design.

- **Comfort and ergonomics:** 50% of respondents rated the handles as "Comfortable, but could be improved," and only 14% found them "Very comfortable." Frequent comments mentioned hand fatigue and grip problems, highlighting the need for ergonomic improvements addressed in Figure 7.
- **Cost and maintenance:** 65% of respondents highlighted affordability and minimal maintenance as key concerns, noting excessive cost as a barrier. To mitigate this constraint, solutions that balance innovation and accessibility were explored, such as lightweight materials, energy-efficient systems, and modular designs that facilitate fabrication and maintenance.

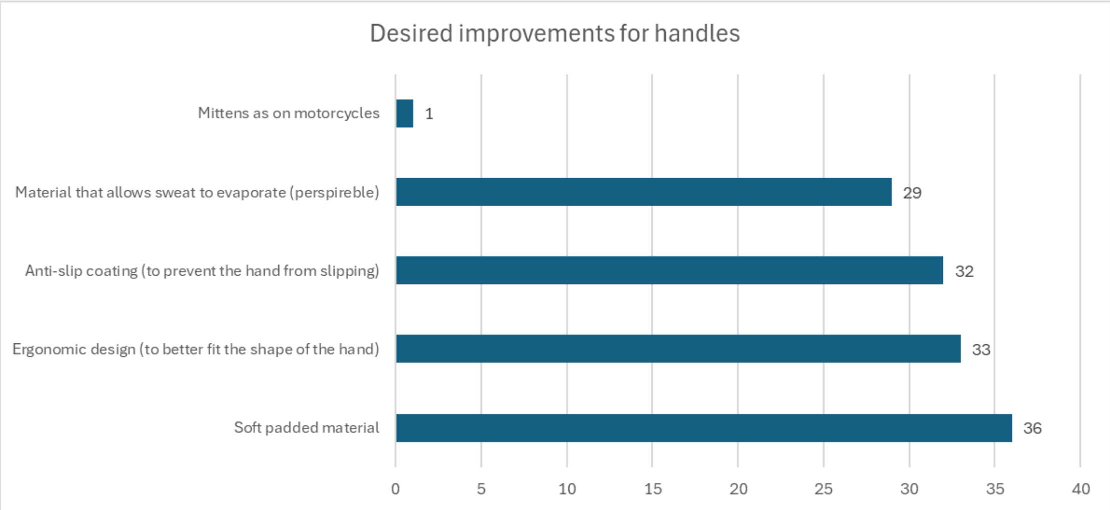

Figure 7 Desired Handle Improvements

The study provides key information for technical and ergonomic analysis, addressing challenges such as weight, safety, cost, comfort, proper use, and fatigue reduction, reflecting the concerns of caregivers and healthcare professionals. The interviews identified key needs such as:

- Delivery protocols: ensuring proper fit of the walker from the start.
- Education and personalised fitting: sessions with physiotherapists to teach its use.
- Follow-up and rehabilitation: initial supervised sessions to facilitate its integration into the daily routine.

Based on these results, developing new walking aids that meet ergonomics, functionality, and safety standards will be promoted, optimising comfort and usability and balancing innovation with economic accessibility.

3.2. RESULTS OF THE COMPONENT DESIGN OF THE INTELLIGENT ROBOTIC WALKER

The design of the smart walker is based on key factors identified in interviews. Health professionals emphasise the importance of proper posture to reduce postural overload. Caregivers and family members prioritise weight, folding, autonomy, maintenance, and cost. Based on these considerations, the following key needs were identified:

- User needs: Consider physical, cognitive, and environmental limitations.
- Safety: Reduce the risk of falls or accidents.
- Usability: Intuitive design, suitable for people with reduced dexterity.
- Portability: Lightweight and foldable structure.
- Aesthetics: It favours acceptance, although it is secondary to functionality.

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The results of the design of the key components of the walker are presented.

- **Structure:** After evaluating different structural configurations prioritising stability, portability, and ease of use, a lightweight aluminium structure with scissor folding was chosen (Figure 8-a), optimising storage and transport without compromising strength. User tests and previous studies supported this choice for its balance between manoeuvrability, stability, and simplicity.
- **Wheels:** Different wheel configurations were evaluated, including four fixed wheels, omnidirectional wheels, and hybrid combinations. After stability and manoeuvrability tests, the configuration with beaver-type front wheels and motorised fixed rear wheels was best rated for facilitating turns, improving control on uneven surfaces, and significantly reducing user effort. The diameter of the wheels influences their stability and ability to overcome obstacles. Sizes 8“-10”, 20 cm and 24 cm were compared, and 24 cm front and 20 cm rear wheels were selected to balance manoeuvrability and stability. Beaver-type front wheels (Figure 8-c) improve steering, while motorised rear wheels (Figure 8-b) optimise traction. Tire material is also critical. While conventional walkers use solid rubber or rubber, this design incorporates solid scooter tyres, which are sturdy, quiet, and puncture-free, ensuring a long service life without frequent maintenance. In contrast, conventional models, which use 8” (20 cm) wheels, only overcome obstacles up to 3 cm, requiring more effort from the user.

  The walker has a solid rubber scooter and quiet, durable, puncture-resistant tyres. They offer a long service life and significantly improve comfort and durability without constant servicing.
- **Handles:** After evaluating different designs based on previous models of commercial walkers, a mixed model between types d and e was selected (Figure 3), the result of which is shown in Figures 8-d and 3b. After evaluation, several models were fabricated in clay, modelled in 3D, and manufactured in resin (Figures 3-a and 3-b). User testing highlighted the comfort and efficiency of the final model: 77.8% chose it compared to 22.2% who preferred the clay model. The developed handles distribute weight evenly, minimising fatigue during prolonged use. In addition, finger grooves improve grip, reducing slippage and pressure.

  The handles have a roughened surface and an anti-slip protrusion to enhance stability and comfort further. They incorporate force sensors at the contact points, which send data to an electronic system with a microprocessor integrated into the walker. This processes the information to detect turning intentions, stops, and anomalies, activating the motorised wheels and safety systems accordingly.
- **Brakes:** The design incorporates two complementary systems: a manual brake and an automatic braking system integrated into the self-programming rear motorised wheels. The automatic brake, electronically controlled, stops the walker safely, preventing slipping on inclined or slippery surfaces. The manual brake, similar to rollators (Figure 3-f), with solid rubber tyres and roughened tyres, ensures slip-free braking. Both systems combined improve stability and prevent accidents.
- **Seat:** The seat of our design was evaluated using surveys (Table 1) with 15 users of both sexes and different heights, who each used it for at least 10 minutes. The Curved Seat with Foam was the highest rated (46.67% preference) for comfort and fit, while the straight seat with gel received no votes. The cushioning comparison confirmed that Foam offers greater comfort and functionality for assisted devices. A durable and washable cover was incorporated for greater durability, thus improving users' quality of life by focusing on their needs (Figure 8-e, 8-f, and 8-g).

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Figure 8. Robotic walker: a) 3D model, b) Rear wheel, c) Front wheel, d) Handles, e) Padding, f) Ergonomic base, g) Seat, h) Backrest, i) Basket, j) Front view of final walker, k) Rear view of final walker.

Combination of seat and padding	Comfort Average	Average Adaptation
Curved seat with foam	4,4	4,27
Curved seat with gel	2,6	2,64
Straight seat with foam	4	3,93
Straight seat with gel	3,67	3,6

Table 1. Results of the seat and padding design study.

- **Backrest:** After evaluating both models (Figures 8-g and 8-h), users preferred the padded fabric backrest for its comfort, durability, and ease of folding. Made from flexible plastic, foam, and breathable fabric, its design with a wide central zone enhances comfort, and the padding adapts to the back without causing pain or fatigue. On the other hand, the cylindrical foam backrest was rated negatively due to its discomfort.
- **Basket:** The metal basket was considered more robust by users, but the bag-type basket was better rated in comfort, with a 99% preference. Factors such as ease of storing and removing items influenced the choice. The metal basket was perceived as small and uncomfortable, while the lighter and more versatile fabric is suitable for daily use. The metal one lacks handles, while the fabric version includes a strap for easy removal and attachment. The standard model's metal basket under the seat protects items but makes access difficult. In contrast, the fabric basket, located at the front, allows easier removal but offers less security against theft. The sports bag-type basket was chosen for its practicality and accessibility. Secured with hooks at the front, it provides good capacity and safe transportation (Figure 8-i). It also includes a luminous strap for night visibility.
- **Electronics:** The batteries and controllers are at the bottom near the wheels. At the top is a blue box containing the controller, screen, and IMU (Figure 8-k). The TOF sensors, shown in red, are just below the seat. The lights and pressure sensors are on the handles, and reflective straps are on the structure, backrest, and bag.

The proposed design differentiates itself from other robotic walkers in several key aspects. While models such as ASAS and SIMBIOSIS use forearm platforms to provide stability, the approach presented in this study prioritises a lightweight frame integrating pressure sensors, TOF VL53L1X sensors, and an IMU BNO055. This combination enables more precise detection of user intent and improved assessment of the distance to the walker, turns, and acceleration.

Regarding accessibility and usability, the design also offers significant advantages over devices such as the IROLLER (19 kg) and the Rehabilitation Robot (82 kilograms) by reducing weight and enhancing the ease of handling in daily use.

The results suggest that the lack of testing in real-world environments may affect the reliability of measurements in everyday situations. To address this limitation, a preliminary analysis has been conducted, considering the application of standardised protocols such as the Timed Up and Go test and the Berg Balance Scale [28], enabling a more accurate evaluation of user stability and mobility.

4. CONCLUSIONS AND FUTURE WORK

The development of the robotic walker presented in this study underscores the importance of integrating ergonomic principles to meet user needs. A comparative analysis of traditional walkers, wheelchairs, and robotic walkers revealed a lack of ergonomic considerations, which guided the design toward a comprehensive and adaptive solution. Adjustability, ease of use, and safety were prioritised, incorporating a modular height-adjustable system, a rectangular structure for enhanced stability, and a vertical folding mechanism for greater convenience in transportation.

Key components such as wheels, handles, seat, backrest, and basket were designed to maximise comfort, functionality, and safety. Notable features include front wheels with springs to reduce vibrations, ergonomic handles with finger support, an anatomically shaped seat made from memory materials, a foldable backrest made of durable fabric, and a sports bag-style basket for easy attachment. Innovative safety elements were also incorporated, including reflective strips, integrated lights, and advanced sensors, enhancing usability and user experience.

To balance automation, ergonomics, and cost, sensors and materials such as durable plywood and waterproof fabric were employed to ensure functionality and commercial feasibility. As a future research direction, integrating LiDAR sensors will improve object detection and the walker's interaction with its surroundings, thereby increasing the device's safety and efficiency.

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