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DESIGN OF A MULTIPURPOSE DEVICE TO SUPPORT DAILY ACTIVITIES

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Abstract. *This paper presents the conceptual design of an assistive device applied to daily living. The design development of assistive devices needs to incorporate health attributes related to safety, comfort, ergonomics, and independence levels. In addition, in the context of a multifactorial domain there is necessary frontier knowledge between engineering and health, specifically occupational therapists. This paper proposes a multipurpose assistive device concept to support daily activities based on a design for assistive technology. The first step, called design cross-domain (DCD), was to lead an interaction with researches on assistive technology to understand the functional profile attended by this kind of assistive technology and a prospection of the patents and commercial products in order to identify limitations and opportunities for design improvement. In the second phase, called conceptual spiral design, methods and techniques were applied in order to obtain the User Requirements to direct the technical characteristics deployment. The use of theory of inventive problem solving – TRIZ – linked to House of Quality from Quality Function Deployment (QFD) supports the exploration of contradictions scenery during the conceptual and technical choices. The resulting most important technical attributes and their relative weights were time to perform tasks (18.2%) and distance from the user hand to the center of mass (15.4%). The observed most relevant technical contradictions were 1) average roughness versus time of use until skin irritation; and 2) distance from the user hand to the center of mass versus length variation. The TRIZ application appointed the inventive principles of segmentation and nesting to resolve these conflicts. The patents and commercial researches indicated the gap of this kind of assistive product in Brazil. The use of a design methodology focused on customization/assistive technology allowed the participation of health professionals and researchers in early design phases, contributing to design learning for both areas, and included an end-user in some discussions after the virtual design.*

Keywords: *design for customization, design methods, assistive technology, universal design, open design*

1. INTRODUCTION

Disability is a complex, dynamic, multidimensional, and contested condition, to which anyone can be temporarily or permanently subjected (World Health Organization, 2011). The impacts associated with this universal challenge transcend the directly quantifiable economic aspects and might include unemployment, social isolation, and psychological problems (World Health Organization, 2011). Whether as a consequence of chronic diseases, genetic malformation, accidents, or aging, it was estimated that between 29.7% and 36.5% of the world population lived with a disability in 2019 (United Nations, 2019; Vos *et al.*, 2020). More recently, the COVID-19 pandemic has also shown to be associated with sequelae that might lead to problems in body function and physical limitations (Daia *et al.*, 2020).

With high prevalence rates worldwide (Brennan-Olsen *et al.*, 2017; Kim and Shinkai, 2017), muscle weakness and joint stiffness restrict mobility and are significantly associated with difficulties in performing activities of daily living (ADL) (Shimoura *et al.*, 2020; Thakral *et al.*, 2014), which explains the fact that musculoskeletal conditions are amongst the highest contributors to global disability (Vos *et al.*, 2020). In this context, the promising area of Assistive Technology (AT) performs an important role, by allowing the development of innovative customized or personalized products and contributing towards the enhancement of functional independence, social inclusion, and quality of life of individuals with disabilities.

Dressing up is among the most disabling activities of daily living (Fettes *et al.*, 2020), especially for people with cognitive impairments or neurodevelopmental conditions (Chu *et al.*, 2019). Since it is also strongly related to self-esteem, the difficulties that arise from the disability might lead to frustration, embarrassment, and decline in quality of life. Over the years, some assistive devices have been proposed to provide dressing aid. Regarding the available commercial products, for example, the most commonly observed designs are centered around dressing sticks (Kinsman, 2013; Maddak, 2008; RMS, 2016), adjustable straps (Fanwer, 2020), or rigid structures (ADVYS, 2017). Each of these cases usually contemplates a specific type of garment (e.g., upper limb clothing, footwear, or underwear). More sophisticated options have also been developed, including for instance robot-assisted dressing (Clegg *et al.*, 2020) and smart clothing (Chu *et al.*, 2019). However, it is important to highlight that these scenarios often introduce certain complexities that might lead to difficulties of adoption for the target user or technology-driven solutions, which are commonly reported reasons for device abandonment (Howard *et al.*, 2020).

Despite the significant demand, the lack of proper assistive devices (ADs) for those in need is substantial (De Couvreur and Goossens, 2011). Besides this deficit, abandonment rates ranging between 20% and 50% have been reported (Sugawara *et al.*, 2018), for reasons that include the neglect of the user's opinions and contexts, poor device performance, ease of purchasing low-quality products, lack of training, and the stigma that associates ADs with medical devices for pathologies (Cruz *et al.*, 2016; Gherardini *et al.*, 2018; Ravneberg, 2012). Therefore, the non-use of an AD might not only hinder social inclusion and rehabilitation but also mean the waste of public resources (Sugawara *et al.*, 2018). In this context, a user-centered design approach allows the development of a customized product, with the individual as the protagonist, whose needs, opinions, and preferences are translated into requirements to be implemented from the early stages of development and throughout the interactions with the different prototype versions.

The classic design methodology theory is focused on the development of industrial products, usually characterized by mass or modular production, and treats the user as a client, whose participation is restricted to the final stages of design, for product evaluation (Cheng, 2018). After extensive design research by Pahl and Beitz (1972, 1977), Verein Deutscher Ingenieure, a German association of engineers, launched the VDI 2221 guideline (VDI, 1987), which aimed to provide a generic approach for the design of technical systems and products in the fields of mechanical, precision, control, software, and process engineering and served as the basis for future approaches to design. The widely used design method proposed by Pahl *et al.* (2007) has a structure similar to this guideline, presenting a similar division into four phases. Ullman (2010) and Ulrich and Eppinger (2015) expanded the coverage of the product development process and added phases at the beginning and/or at the end of the method, but still maintained a very similar structure (Motte *et al.*, 2011).

Despite being consolidated, the traditional methods were proposed for contexts in which the dominant culture is one of cost-cutting and problem solving, in which innovation is driven by technology, and in which thinking follows an orderly and linear logic (De Couvreur and Goossens, 2011). On the other hand, the design of an assistive device must reflect the physical, cognitive, and emotional needs of the user, while also engaging all stakeholders in a specific context. Therefore, designing an AD fundamentally differs from mass production products, demanding a user-centered approach and collaboration between engineering and health professionals to reduce the currently high abandonment rates. Moreover, such teamwork combined with technologies such as additive manufacturing allows the generation of prototypes in different design phases, more effectively including the user in the design process (Santos and Silveira, 2020).

Even though efforts have been directed towards the proposal of methodological approaches for AT design (Coton *et al.*, 2014; Gherardini *et al.*, 2018; Manero *et al.*, 2019; Okumura and Júnior, 2015; Schwartz *et al.*, 2019), the application of design tools or techniques is often scarce or not explicitly described. These tools might provide means for the design team to develop devices with higher acceptance rates, by considering the user not only a customer but a co-designer, who actively participates throughout the process. Therefore, a systematized user-centered design process, with the implementation of the appropriate design tools, allows the user needs to be incorporated in the early stages of development and facilitates communication and interaction between all parties involved, potentially contributing towards the improvement of the final device in terms of satisfaction, cost, functionality, and innovation (Santos *et al.*, 2019).

This paper conducts the conceptual development of a device to assist activities of daily living that involve dressing up and reaching objects. The AT-d8sign methodology was adopted (Santos and Silveira, 2020), which is an iterative systematic design process focused on a user-centered approach to customization. By following an appropriate design framework, applying the relevant tools and techniques, and thoroughly considering the end-user needs, opinions, and preferences, the authors intend to enhance long-term adoption of the device and address the current gaps that exist in dressing aid products, especially in terms of simplicity, comfort, and adaptability.

2. MATERIALS AND METHODS

The device design development was based on the AT-d8sign methodology proposed by Santos and Silveira (2020), whose focus is to include the different actors (e.g. health professionals, end-user, and engineers) in design development, mainly in early phases with intersection of domains and conceptualization. Since this work was focused on the generation of concepts and not necessarily of a physical prototype, the evaluation and refinement stage of the adopted procedure was not implemented in this paper. Therefore, the application of the iterative and interactive nature of AT-d8sign is beyond the scope of the present research and will be the subject of further investigation.

2.1 AT-d8sign methodology

This design methodology was proposed by Santos and Silveira (2020) and the case study was focused on Assistive Technology. The first phase is the so-called "Design Cross-Domain" – DCD, in which the health professional's contribution is fundamental. The second stage is the conception spiral, in which the concepts and solutions are elaborated and perfected. In the final stage, the user participates through an occupational therapy assessment tool in order to evaluate and refine the device.

During the design cross-domain, the health professional's contribution is fundamental to define the knowledge, skills, and experiences in order to develop the solution. This stage is composed by four phases:

- Design domain identification: knowledge and experience definition, according to the characteristics of the AD. It should be added to the DCD through its user representatives and the user;
- Design domain integration: collection of the different experiences from the related knowledge fields involved in the design. Creation of a language common to DCD. Design objectives, goals, and visions definition;
- Study of the background: research and analysis of the technique and state of the art related to the AD (patents and commercial products). Survey with the user, focused on past experiences with the related AT. User's disability characteristics and limitation analysis, considering the context in which the user is inserted;
- Schedule plan: definition of the basic activities schedule, with goals and deadlines, in order to integrate, encourage, motivate, and guide the professionals and the process.

After performing the design cross-domain procedures, the conception spiral is started. This is the most creative stage and its objective is to elaborate and improve the solutions through design techniques, such as additive manufacturing, mock-ups, prototypes, and products. This stage is also composed by four substages:

- Design requirements definition: identify the user requirements, expectations, and desires, and select the most important ones. Definition of the technical design parameters and restrictions;
- Concepts generation: improve the problem and the design demand understandings, using feedbacks obtained by user evaluations and design tools and techniques, in order to generate and improve the AD concepts and solutions;
- Virtual models development: creation and improvement of the AD virtual models (CAD), based on the first sketches and on the feedback obtained by the user evaluations. Perform CAE analysis. 3D scanning of objects or body parts, when applicable;
- Materials selection and prototype manufacturing: analysis and selection of the most suitable materials. Manufacturing of mock-ups and prototypes. Additive manufacturing techniques can be used, in which case the 3D printer shall be selected and the process parameters calibrated.

The final stage aims to evaluate the user and DCD members satisfaction and then refine the AD functionality and effectiveness. The evaluation result feeds back the conception spiral phase in order to refine the design solution. This stage is also composed by four substages:

- Concepts presentation: demonstration of the AD proposed solutions to the other DCD members, through the adequate means available (sketches, drawings, mock-ups, prototypes, etc.);
- Adaptation phase: the close observation of the user during the initial adaptation to the AD is critical. Training of the user and party concerned regarding the AD proper usage;
- Qualitative and quantitative tests: identification and selection of the most appropriate assessment tools. Perform qualitative and quantitative combined test in order to measure user satisfaction and AD functionality and effectiveness, from the technical and therapeutic standpoint.
- Delivery and follow-up phases: deliver the final product to the user whenever possible. Follow-up in the long-term in order to identify necessary adjustments and maintenance. Continually improvement of the solution through open-source designs, when applicable. Elaboration of patents, depending on the circumstances.

2.2 Design cross-domain (DCD)

The target users of the assistive device to be developed are mainly people with restricted mobility in the upper limbs and with difficulty in reaching objects located farther than one-arm distance. Mechanical and materials engineers composed the design team. An occupational therapist and a physiotherapist were consulted throughout the design process to account for interdisciplinary collaboration and for a multifaceted background constructed from different knowledge areas. The design domains were integrated through remote meetings, interviews, and brainstorming sessions.

Aiming to deepen the understanding of the state-of-the-art regarding the assistive device to be developed, the design team mapped the commercially available products from websites of relevant resellers and manufacturers. In addition to the market research, the ESPACENET database was consulted for identifying patents pertinent in the field. The strings "assistive" AND ("apparatus" OR "device") AND (("wear" OR "clothing") AND ("socks" OR "shoes")) were used in this stage to account for different types of garments and to allow the detection of opportunities for improvement and innovation.

2.3 Conception spiral

After design domains identification and integration, study of the background, and establishment of overall goals and deadlines, the conception spiral design phase was initiated, characterized by its cyclic and iterative nature directed towards elaboration and improvement of product concepts and solutions. In this step, the House of Quality (HoQ) from Quality Function Deployment (QFD) was chosen as design structure method. The HoQ is the first matrix that performs operations of extraction, correlation, and translation between the user and technological domains. The results of the matrix process is the prioritizing of the technical characteristics based on user's requirements (Rianmora and Werawatganon, 2021).

From user shadowing and iterative deliberations with the collaborating physiotherapist and occupational therapist, the design team defined the user requirements for the device. Each of these preconditions was subsequently translated into one or more technical attributes with its corresponding units. The QFD relationship matrix was then constructed by assigning a number (0, 1, 3, or 9) to categorize the relationship between the user requirement i and the technical attribute j as non-existent, weak, moderate, or strong, respectively.

Both health professionals that have been consulted throughout the development process were required to rate the user requirements according to importance. A pairwise comparison method with binary scale was conducted to assure a more objective and systematized analysis (Ramík, 2020). The design team also organized the ranking, such that each of the three groups (engineers, physiotherapist, and occupational therapist) was blinded in regards to the others' classifications. Requirements were then categorized as unimportant, important, or very important, and were assigned the corresponding numbers 1, 3, or 9, respectively. The overall importance weight for each user requirement was calculated as the average of the groups' grades. For each technical attribute, the overall importance weight was determined from Equation (1):

$$I_j = \sum_{i=1}^{n} w_i C_{ij}, \tag{1}$$

where I_j is the importance weight of the technical attribute j, w_i is the importance weight of the customer requirement i, and C_{ij} is the relationship between the customer requirement i and the technical attribute j (Wasserman, 1993).

The subsequent step was to construct the QFD correlation matrix for identification of the interrelationships between technical attributes and detection of design contradictions. Following an integrated approach, the Theory of Inventive Problem Solving (TRIZ) was used to propose creative solutions based on the correlation matrix (roof of the QFD). Each contradiction arising from the QFD (when improving one technical requirement worsens another) was translated into a pair of engineering parameters to create a general problem that subsequently could be solved by one of the principles of invention. The most suitable principles for each contradiction were indicated by Altshuller's Table of Contradiction, as suggested by Navas (2013).

Having a wider and deeper understanding of a product's use is extremely important to a well-designed process. Therefore, a Functional Decomposition and a flow of Material, Energy and Information (MEI) were applied to the Conception spiral design phase. Functional Decomposition is a recursive technique to relate the functions of a product to its final user. This technique identifies a main function and as many sub-functions as necessary to completely define the use of a product. As for the MEI diagram, it is a process that identifies the features of a product operation by highlighting the separated flows of material, input and output of energy and necessary information to perform the function (Fiorineschi *et al.*, 2018; Mattson and Sorensen, 2016; Ullman, 2010).

Project parameters and their respective solution principles were placed in the Morphological Matrix. In this step, TRIZ-based solutions were added. Then, two overall solutions were created by systematic combination of the solution principles for later choice based on the FMEA.

The Failure Mode and Effects Analysis technique (FMEA) was also applied to the Conception spiral design phase to identify possible failures and their causes and effects. This process diminishes the likelihood of processes or products to fail, increasing their reliability. If FMEA is applied to a product, it identifies failures that might happen during operation, whereas if FMEA is applied to a process, it identifies failures that might happen during manufacturing and/or assembling. This paper applied FMEA to the product. More information about this technique can be found in Spreafico *et al.* (2017), Stamatis (2003) and Wu *et al.* (2021).

Once the concepts were generated, the virtual models were developed using the Inventor® software. An Ashby chart of Young's modulus versus density was used to guide material selection for the device, with the aim to obtain a viable relationship between low density and high stiffness, with adequate mechanical strength for the desired application. Regardless of the material to be used for manufacturing the final product, the first version of the physical prototype will be fabricated mainly for preliminary user testing, aiming to obtain feedback regarding geometry and adopted mechanisms. This initial mock-up will likely be subjected to multiple iterations and adjustments before reaching its final configuration. Therefore, the manufacturing process in this stage must be quick and of easy intervention. Additive manufacturing presents great potential in this scenario, besides allowing geometric parametrization and straightforward design alterations. As previously mentioned, the generation of a physical prototype is not covered by the present work, but an analysis to guide material selection for the 3D printed device was conducted. Literature-based tensile testing results regarding the three most widely used commercial filaments (PLA, ABS, and PETG) were evaluated, and the most adequate polymer was chosen.

3. RESULTS AND DISCUSSION

Ease of handling, cleaning, and maintenance, comfort, and the non-occurrence of skin irritation are general requirements that must be satisfied by the majority of assistive devices and are covered by the attributes of independence, ergonomics, and safety. In addition to these universal features, the specificities of presenting an adequate weight, enabling multitasking, being firm, durable, and portable, and allowing length adjustment also composed the set of user requirements for the device to support activities that involve dressing up and reaching objects.

Figure 1 presents the House of Quality results, with the previously mentioned user requirements and the corresponding translation to technical attributes and assigned weights. It is possible to observe an overall consistency along the importance rates designated by the three groups (design team, occupational therapist, and physiotherapist), which indicates efficient communication between the different parties involved and a good understanding of the user context. Two items, however, must be discussed in greater detail. Not causing skin irritation was considered a very important requirement by the health professionals, but was treated as unimportant by the engineers. This discrepancy can be explained by the fact that the design team conceived the device usage to occur during a short time (e.g., for putting clothes on), which minimizes contact with the user skin, reducing the importance of this requirement from the engineering perspective. Another worth-highlighting aspect is the specification of device firmness, which was assigned a different weight by each group. This variance might be a consequence of the different backgrounds associated with the stakeholders and the subsequent possibly diverging understandings of what being firm means, which reinforces the need for standardized definitions before weighing requirements importance. An engineering weight of 1.5 was assigned to the firmness requisite to counterbalance this effect.

	User requirements \ Technical attributes	Time to perform tasks [s]	Distance from the user hand to the center of mass [m]	Mass [kg]	Contact area [m²]	Average roughness [µm]	Time to clean [s]	Number of interchangeable tips [units]	Stiffness [N/m]	Length variation [m]	Number of standardized parts [units]	Service life [hours of use]	Time of use until skin irritation [min]	Compaction index [m/m]	Minimum volume [m³]	Design team	Occupational therapist	Physiotherapist	Evaluation result	Engineering weight	Final result
1	Ease of handling	●	●	▽	▽			▽								9	9	3	9	1	9
2	Light	▽		●					▽							3	1	1	1	1	1
3	Comfortable		▽	▽	●	●							○			3	3	9	3	1	3
4	Ease of cleaning					●	●									1	3	3	1	1	1
5	Multitask						▽	●		○						3	1	1	1	1	1
6	Firm			○					●	▽				○		9	3	1	3	1.5	4.5
7	Adjustable length		○						▽	●				▽		3	3	3	3	1	3
8	Ease of maintenance										●					1	1	1	1	1	1
9	Durability	▽						▽				●				3	1	3	1	1	1
10	Not to irritate skin	○			▽	○							●			1	9	9	9	1	9
11	Portability			○				▽		○				●	●	1	3	1	1	1	1
	Absolute weight	110	93	37.5	45	63	10	20	44.5	37.5	9	9	90	25.5	9						
	Relative weight	18.2%	15.4%	6.2%	7.5%	10.5%	1.7%	3.3%	7.4%	6.2%	1.5%	1.5%	14.9%	4.2%	1.5%						

Relationship conventions	Strong 9 ●	Moderate 3 ○	Weak 1 ▽

Figure 1. Relationship matrix.

The categorization of the relationships between user requirements and technical attributes as strong, moderate, or weak can also be observed in Figure 1. After performing the appropriate calculations, it was possible to infer that the two most important technical attributes were time to perform tasks and distance from the user's hand to the center of mass, with relative weights of 18.2% and 15.4%, respectively. These findings allow the identification of the features to be prioritized throughout the design process.

Once the relationship matrix was constructed, the development of the correlation matrix allowed the detection of technical contradictions. Figure 2 displays the QFD “roof” and presents the direction of improvement for each technical attribute, whether the goal is to maximize the feature, minimize it, or maintain it within a specific range. For each pair of characteristics, the correlation was categorized as positive, negative, or non-existent. A technical contradiction exists whenever the directions of improvement are the same, but the correlation is negative, or the directions of improvement are opposites, but the correlation is positive. Through careful analysis of Figure 2, it was possible to identify the technical contradictions for the desired device, described as: distance from the user’s hand to the center of mass (column 2) versus length variation (column 9); average roughness (column 5) versus time of use until skin irritation (column 12); and length variation (column 9) versus service life (column 11). For further treatment, the two most relevant contradictions were selected as those with the highest sums of the relative weights of the corresponding technical attributes as calculated in the House of Quality. Therefore, the inconsistencies 2-9 and 5-12 (with the numbers representing the columns in Figure 2) presented relative weights of 21.6% and 25.4%, respectively, and were used as input for TRIZ application.

The first contradiction to be resolved was to improve the time of use until skin irritation (column 12) while avoiding worsening the average roughness (column 5). The assigned Altshuller’s engineering parameters were harmful side effects (parameter 31) and convenience of use (parameter 33), respectively. For the other inconsistency, it was desired to improve the distance from the user’s hand to the center of mass (column 2) while avoiding worsening the length variation (column 9). The designated engineering parameters were stability of object (parameter 13) and adaptability (parameter 35), respectively. Table 1 shows the principles that potentially assist in the resolution of these conflicts.

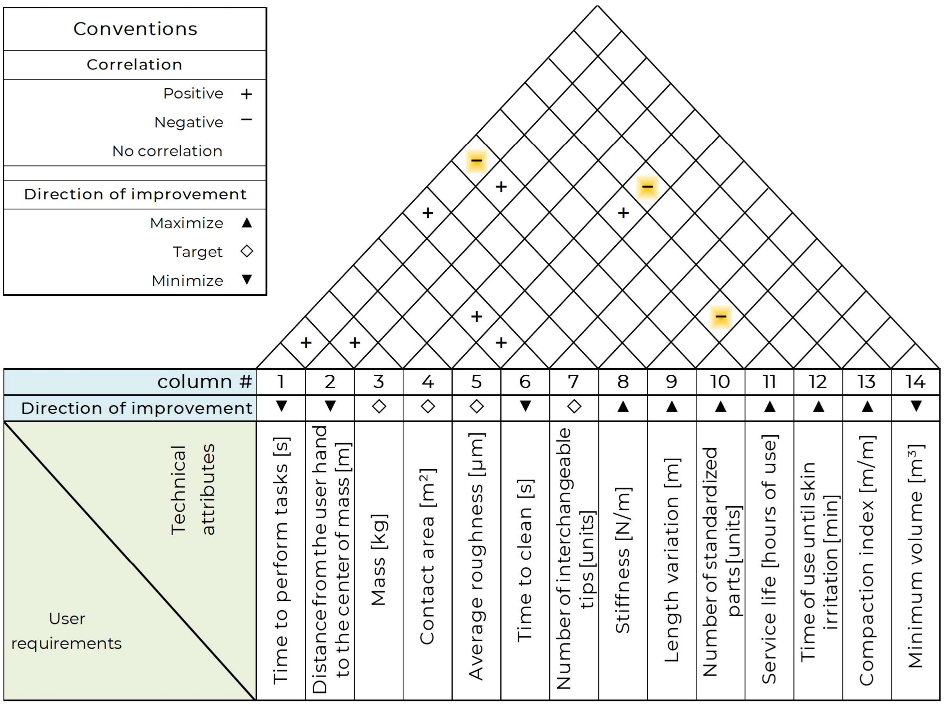

Figure 2. Correlation matrix.

Table 1. Principles of innovation that potentially resolve the matrix of contradictions.

Technical attributes translated into engineering parameters		**Degraded technical characteristics** 33. Convenience of use	35. Adaptability
Feature to be improved	31. Harmful side effects	3 – Local quality 24 – Mediator 31 – Use of porous materials	---
	13. Stability of object	---	35 – Transformation of the physical and chemical states of an object 2 – Extraction 7 – Nesting 1 – Segmentation 3 – Local quality 8 – Counterweight

The application of QFD and TRIZ tools provided means for appropriate and systematized identification, prioritizing, and treatment of design requirements. The obtained outcomes of the most relevant technical attributes, the most critical technical contradictions, and the most promising inventive principles provided a solid foundation in which to develop the concept generation stage of the design process. Subsequently, the implementation of functional decomposition and the development of the MEI diagram contributed towards deepening the understanding of the fulfillment of the activities involved and of the user-device interaction. Resulting from this broad background and from brainstorming sessions, Table 2 presents the parts that compose the device and multiple possible design alternatives for each one. All proposed concepts are based on a stick with a length variation mechanism and interchangeable tips to allow multitasking execution. The TRIZ-derived inventive principles of segmentation, nesting, and local quality were embedded in the propositions. Two solutions were obtained from this morphological matrix. Solution 1, represented in column 4 (blue background) of Table 2, presents a solution using polymeric material and an anatomic handle with no coating. Snap-fits are used for adjusting length and binding the tip to be used and the stick. Solution 2 (column 2 of Table 2, gray background), on the other hand, is mainly composed of aluminum and contains a cylindrical handle with a neoprene coating. The tip-stick assembly and the length variation are accomplished through pins.

Table 2. Morphological matrix.

Parameter	Solutions					
Tip-stick union system	Pin-fixed tubes	Conic assembly (friction)	Snap-fit	Magnetic	Thread	Adhesive
Stick material	Aluminum	Wood	Polymer	Steel	Bamboo	---
Tip material	Aluminum	Wood	Polymer	Steel	Bamboo	---
Handle shape	Cylindrical	Oval	Anatomic	---	---	---
Handle coating	Neoprene®	Leather	No coating	Foam	Fabric	---
Length variation mode	Concentric tubes with pins	Foldable with pins	Concentric tubes with snap-fit	Concentric cones	Tip with long stick	Accordion fold

After conceptualizing the two solutions, the application of the FMEA (Failure Mode and Effects Analysis) technique allowed the identification of the potential failure modes and their corresponding causes and effects. The FMEA deployment is presented in Table 3, with Severity (S), Probability of Detection (D), and Risk Priority Number (RPN) values detailed for the two conceived solutions.

Table 3. Conceptual FMEA.

Device subset	Failure mode	Cause of failure	Effect of failure	Solution 1			Solution 2			Design guidelines
				S	**D**	**RPN**	**S**	**D**	**RPN**	
Tip-stick union system	Wear	Material removal with frequent use	Non union	8	5	40	8	4	32	Reduce surface roughness
	Fracture	Excessive load during usage	Premature union release	8	7	56	10	6	60	Avoid loose fittings
Stick material	Fracture	Excessive load during usage	Loss of function	10	8	80	9	4	36	Perform topology optimization
		Crack propagation under cyclic loading	Loss of function	10	10	100	10	10	100	Minimize stress concentration
Tip material	Fracture	Excessive load during usage	Loss of function	10	9	90	9	6	54	Perform topology optimization
		Crack propagation under cyclic loading	Loss of function	10	10	100	10	10	100	Minimize stress concentration
Handle coating	Wear	Material removal due to friction or chemical degradation	Coating removal	0	0	0	3	1	3	Provide proper adhesion
Length variation mode	Fracture	Excessive load during usage	Device no longer varies in length	7	7	49	7	6	42	Avoid loose fittings
				∑		**515**	∑		**427**	

The Probability of Occurrence was not considered herein since it is often determined based on previous failure observations, and this data is not available for a to-be-developed product. The device subset handle shape was not included in the analysis since the authors concluded that there would be no score difference between the two solutions regarding this criterion. Therefore, it would not be relevant for the comparison between the two solutions. It is possible to observe from Table 3 that Solution 2 presented the lowest overall score, being the less susceptible to failure, which justifies selecting this configuration as the optimal device design. General design guidelines were proposed to minimize the predicted failure effects.

The virtual model related to the final conceptual design is presented in Figure 3. It allows observation of the different parts (handle, stick with length adjustment mechanism, and tip) through the exploded view (Figure 3a) and of the multiple conceived tips (Figure 3b) for a variety of garments, including shoes, socks, and lower and upper limb clothing.

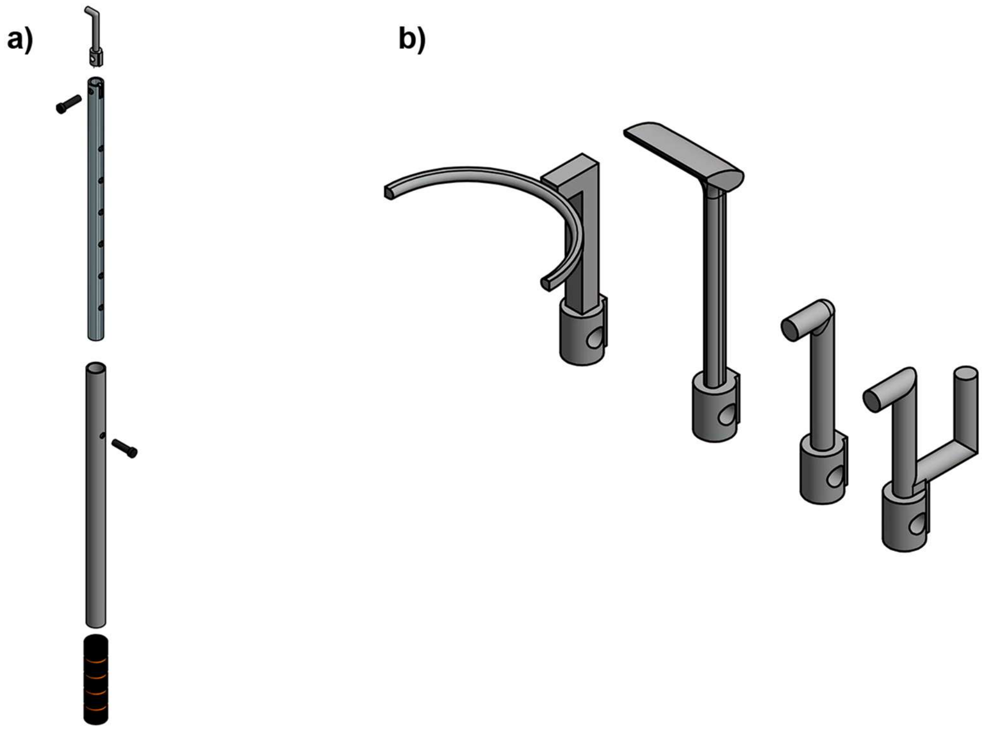

Figure 3. Exploded isometric view (a) and tips (b) of the proposed conceptual solution.

The decision to use aluminum to compose the final device was guided by the Ashby chart of Young's modulus versus density. The selected metal and its alloys enable the construction of a product that meets the requirement of increased stiffness while maintaining its mass within a range of desired values. Scientific and technological studies based on mechanical performance of feedstock in solid state (filament) used in desktop 3D printer (Fused Filament Fabrication, FFF technique) report the performance of 3 types of polymers: PLA (Polylactic acid) filament supports greater static load, but does not present large deformation before rupture, being characterized by a mostly brittle behavior (Portela, 2017). Comparatively, the ABS (Acrylonitrile-Butadiene-Styrene), a copolymer filament, endures less static load but is more ductile, presenting a much larger deformation period. On the other hand, PETG (Polyethylene terephthalate) demonstrates an average behavior in terms of resistance to static loading and has a considerable absorption capability before reaching the tensile strength. Therefore, the material selection study appointed PETG as the most indicated filament for the to-be-manufactured prototype, since it encompasses more printing possibilities and presents greater mechanical behavior.

4. CONCLUSIONS

This paper presented the development process regarding the conceptual design of a device to assist activities of daily living that involve dressing up and reaching objects. A design for customization methodology was adopted, leading towards a product that reflects the physical, cognitive, and emotional needs of the target user, besides engaging all stakeholders in a specific context. After implementation of this systematized procedure and of the proper design tools and techniques, the proposed solution addressed some existing gaps regarding similar assistive devices, especially in terms of portability, adaptability, and multitasking capability, through the features of a length adjustment mechanism and interchangeable tips. The design methodology allowed the establishment of a more active interaction between the different design members as well as the external actors (end-user and clinical therapists), promoting in fact an interdisciplinary design environment. The virtual model presents the design concept developed for the assistive device to help people with reduced motor function in the definition of various pathologies. The proposal has a satisfactory evaluation by the research group on Occupational Therapy at the Federal University of São Carlos, with which there are previous projects focused on Assistive Technology. According to Martinez, L. B. A. (professor and researcher at UFSCar, Department of Occupational Therapy): "Since dressing up is a complex activity, with multiple steps and variables, which requires from the individual specific capabilities and skills, one of the main advantages of the proposed device is its versatility. The adjustable stick and the diversity of interchangeable tips ease the performance of multiple tasks that compose the act of dressing up; allow device individualization; and enable adaptability to different situations and garments. The features and adjustment possibilities may assist elderly and people with disabilities or restricted mobility to become more independent, favoring autonomy and quality of life".

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