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Interdisciplinary Contributions in the Design of Assistive Products With 3D Printing Technology

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Abstract – This work shows an interdisciplinary approach between product design, psychology, and electronic engineering disciplines. The contributions, knowledge, and results for the creation of assistance products from this research process are focused on the principle of inclusion of people with disabilities. The review of the scientific literature on the topic addressed is related to human-centered design from a comprehensive vision that recognizes needs while respecting the principle of individuality. The hypothesis suggests that products designed for individuals with disabilities gain significance when developed through an interdisciplinary approach within the context of collective knowledge-building. This process was carried out using additive 3D printing technology. We worked through a case study and functional prototyping of an upper torso exoskeleton and arm exoprosthesis for people with the total absence of both upper limbs. This project's main objective is to offer accessible resources that improve the quality of life of people with physical disabilities. The main results are an iterative synergy between the actors, a functional and personalized product, and a valorization of assistive technologies and materials for a practical design.

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1. Introduction

Inclusion has been a topic of analysis for decades, and it still forms a prioritarian part of the global social, political, and formative agendas to address the integration and inequality of individuals and priority groups within society [1].

In Ecuador, of the 471.205 people with disabilities registered in 2022, the physical type represents 45.66% [2]. This creates an opening for the design of systems and assistance products poorly developed in the country [3] which are internationally recognized at a normative level (ISO 9999, 2023) [4] at the same time that is considered emerging from the global objectives and sustainable global goals SDG, this in particular from the aspects of health, well-being and its approach of quality of life, equity, and inequality [5].

This is how the management of knowledge, creativity, technology, and social responsibility merge in the context of university Higher Education; the Pontificia Universidad Católica del Ecuador (PUCE) developed actions to promote human dignity and social transformation [6].

The career in product design at this institution, as an agent of change, established for its end-of-degree semester projects and as one of its lines of action, the creation of technology-based products and services linked to 3D printing, that support people with disabilities in general, promoting dynamics of diversity participation.

Through a case study, the user is placed at the center during the design of an experimental and functional [7] prototype system of the upper torso exoskeleton and an articulated exoprosthesis of the arm through 3D printing technology, in an interdisciplinary way, for people with a total absence of their upper limbs.

2. The Current State of 3D Printing Applied to Exoprosthesis

The use of 3D printing technologies in the prototyping of custom-made prosthetic products of complex anatomies dedicated to replacing a body part has been increased and is projected as part of the future of additive manufacturing in the medical industry [8]. The education field has undergone a revolution with the advent of technological solutions that aid in improving essential functions for people with disabilities. These solutions promote autonomy and accessibility while utilizing open-source code and reducing manufacturing costs. It has also discussed, to a lesser extent, the bond between the user and the product [9], [10], which is particularly interesting since this article is essentially the emotional well-being and the customized adaptation above the approaches mostly functional that persists on engineering, biomechanics, materials sciences among others; or similar courses focused on prosthetic rehabilitation available on the field of physical medicine.

In association with these various fields of action, it generally unfolds on descriptive studies about digital modeling and three-dimensional printing technics, the chosen materials [11], and the resources used. Inquires about the adaptive progression of patients based on medical or therapeutically goals are also added.

The present project is considered relevant since it contributes to the existing studies from the design centered on the human being. It promotes university teaching methodologies based on addressing complex challenges using 3D printing technologies, emphasizing practical application through real-life case studies.

3. Challenges in the Areas of Product Design, Technologies, and Human Beings Related to the Absence of Upper Limbs

The amputation of both upper limbs at the level of the shoulders is called shoulder disarticulation, and trauma is the preliminary cause worldwide, with ciphers that exceed in men 3:1 to women [12]. Such data motivate a selective choice of the study subject, focusing on the most affected population.

Another reason is the feasibility of an observant throughout the design process, which offered permanent feedback from his personal experience of a total amputation caused by accident, to support the creation of products that improve users' quality of life with similar necessities.

Regarding the development of prosthetics for people with this diagnosis, it is found that the studies are scarce, taking into consideration anatomical-functional restrictions, psychological health, and broad technological challenges.

The extent of functional dependency, according to Barthel's classification [13], which measures the performance of individuals related to daily-basics activities, is considered moderate in the cases of upper bilateral amputations. For this reason, the main problem, it sought positive influence from the design on aspects of the absence of autonomy and to support the performance in the daily-basic activities such as eating, drinking, using the bathroom, and getting dressed, that the people with an impairment or reduced mobility do with the operational support of family and close friends.

At an anatomic level, the challenges of the system integrated by the arm, forearm, and hand are also highly regarded due to the various movements included in creating an exoprostheses of upper limbs. One must consider other elements, the multiple degrees of freedom to achieve supination and pronation linked to the rotation movements of the forearm and hand so that the palm remains upward or downward. In addition, the typology of cylindrical and tweezer grips and the particular and independent mobility of the fingers is also essential.

Regarding technological function, arm prostheses generally require a mediating interface with the human being through insertion or socket. This implies considering pieces for fixing the arms, which typically coincide with a support on the torso.

The challenges for the creation of the prosthesis are not only disciplinary. It is not a question of choosing a challenge from a reductionist vision that divides the problem but of integrating ideas and ways of thinking with a holistic conception [14] that recognizes, in this case, the individualization of the user, the technological use and relevant materiality, aesthetics and morphology, proper use and adaptation at a psychological and emotional level, among other aspects; also maintaining accessible costs and achieving the desired functionality concerning needs that derive from a complex problem.

That is why creative thinking and interdisciplinary collaboration are requested for the design, which from its macro-opportunities, allows addressing innovative technology-based projects [15] and that by transcending the limits and perspectives of a single discipline or area of instruction also project a greater sense of responsibility and quality [16].

4. Interdisciplinary Contributions for the Design of Exoprostheses: Fields of Action and Relations

Working with professionals from complementary areas under interdisciplinary collaboration agreements allows moving from the abstract to the concrete, addressing problems from different points of view, translating into an instrumental understanding that requires a dynamic theoretical-methodological integration [17].

In the case of an exoprosthesis and for its development, there is a demand for social, project, and technical knowledge related to the fields of action of psychology, product design, and electronic engineering, respectively. In this sense, the higher-level educational context favors fulfilling the challenge. It places the Pontificia Universidad Católica del Ecuador, PUCE in Quito as a scenario of interaction for change and innovation.

From the PUCE research group Psychology, Inclusion y Cohabitation (PSICO), the exoprosthesis project of upper limbs is filed. Their experiences with disability cases show the need for emotional support from psychology, but they also refer to the importance of having tangible assistance products for these vulnerable groups.

Thus, the educational system is committed with its teachers, researchers, and university students so that they support research studies or applied projects necessary to eliminate barriers and reduce existing gaps. This is within the inclusion framework and under a vision based on the possibilities, not on the weaknesses of people with disabilities [18].

The product design career of the Faculty of Architecture, Design, and Arts of the PUCE develops technology-based assistance projects through its line of research in Design and Interdisciplinarity (INDIS). That is why collaboration between PSICO and INDIS was agreed upon to generate benefits for people with impairment while strengthening the students' formative research and project training.

In this sense, it was decided to contribute with a project applied from product design as a creative, technical-project, and strategic discipline. Thus, a career student assumes the challenge of conceiving an experimental functional prototype of upper limb exoprosthesis in the framework of her final degree project.

Due to the complexity of the macro-project and the functionality it demands, an expert in electronic engineering from PUCE joins the team.

As a technical advisor, he operationally contributes to the student solving problems related to integrating components in the prosthesis such as sensors, Arduino, servomotors, and electronic and digital systems, among others.

The collaboration of these three disciplinary fields finds common approaches based on practice and with a view to the human being as the center.

In the case of product design, the Human-Centered Design (HCD) approach is recurrent, whose premise is that the project is guided based on knowledge and understanding of the individual's experiences, desires, limitations, and needs [19]. Humanity-centered design is added, which advocates co-designing with the human being from an integral vision and not only for the human being as an isolated social subject [20].

From psychology, a similar approach is shared under the principle of individualization. The recognition of the person as a unique and unrepeatable being that requires the recognition of their particular needs is pointed out, allowing them to provide the resources and support for their inclusion in the social sphere.

Electronic engineering coincides methodologically with product design in a problem-based teaching-learning approach (ABP), consistent with applied, critical, collaborative, iterative work that combines aspects such as decision-making from the academy for the progressive and operational generation of the design [21].

5. Development of the Technological Project, Research, and Ideation

The project's development begins with a research process where the parties define the approaches and apply various inquiry techniques.

The first action is an interview with an Ecuadorian engineer with more than five years of expertise in creating exoprostheses and medical equipment with 3D printing technology. To record the working times, limitations, and relevant data based on the experience of interacting with users and critical actors; likewise, about approximate costs of materials, types of measurements used, and computer-assisted programs, among others.

Subsequently, a focus group is developed with six members of the PUCE university context: students, researchers, research assistants, and teachers whose objective is to identify priority activities, learn about the concerns and daily routines of a male university study subject, with the total absence of upper limbs and who voluntarily joins the focus group to comment on their experience and offer data that improves their condition and the quality of life of people with similar diagnoses.

They have added: a person from his immediate environment who helps him with some essential functions, an industrial design teacher-researcher as a moderator or the product design career, a psychology professor and researcher from PUCE with experience in projects that promote inclusion of people with impairments; finally, the product design student who will develop the project.

A measurement process continues for which a high-resolution 3D laser scanner POP2 Revopoint is used, which through the Skanect Pro program creates a custom 3D model of the study case torso to create an exoprosthesis that fits precisely to the existing stumps, with approximated measurements of the arm lengths and muscle volumes. For this process, the 360-degree scanned postures are seated, on a backless support, and in a relaxed position, naturalizing the posture to facilitate the posterior fitting of the prosthesis. The technological contribution is relevant since scanning offers improvements over traditional body measurement techniques developed with plaster modeling that implied longer interaction times and invasive skin contacts for data recording.

The scanner measurements are complemented with reference measurements taken for the scaling process fidelity, detailed photographs of the subject's torso, anthropometric and anatomical bibliographic research, and range of movement in arms and hands according to various references [22], [23].

The study of references is also established as a source of value to know similar cases of 3D printed prostheses with their successes and failures. Experiences in developing prototypes by the Applied Physics Laboratory (APL) of Johns Hopkins University in the United States [24] with notable advances in prosthetic muscle control were reviewed. Hand prototypes developed by the Ecuadorian company Jubilous 3D & Icarus were also studied. Functional models mainly focused on hands and arms coming from degree theses from Ecuador, Australia, and Spain were investigated [25], [26], [27].

The search reports the use of various programs. The SolidWorks is used for the simulation of movements, calculations of effort in grips, and analysis of joint tension between pieces. Blender is also used, due to the feasibility of modeling organic parts, the free program, and the improvement in the performance of the instructional equipment.

The use of filaments for printing coincides with Acrylonitrile Butadiene Styrene (ABS) and Polylactic Acid (PLA), flexion systems are also implemented in hands by rope tensioners, and the use of Arduinos and servomotors.

The studies highlight the cost reduction provided by the use of 3D printing technology together with an agile and personalized prototyping process. Finally, exoprostheses are generally designed using shell-type compartments to accommodate functional components.

Among the mistakes are isolated cases of oversizing in shoulder width. This is due to the functional and size constraints of electronic components. Likewise, exoprosthesis 3D prototyping processes are recurrent, mainly from the academy, the results of which are primarily related to institutional budgets and the technological capacities installed in universities.

At the end of the investigative phase, an interview is carried out with the electronics expert from the PUCE and a technical assistant in the prototyping laboratory of the university. It seeks to know the available 3D printing technological equipment, types of electronic components, the feasibility of acquisition, and their modes of operation applied to creating exoprostheses.

As a result, the investigation gives insights to go to a second project instance called Design as Conceptualization. In this phase, the first creative solutions are established using the DNA and Moodboard ideation techniques [28], which lead to the sketches and development models [7] shown in Figure 1.

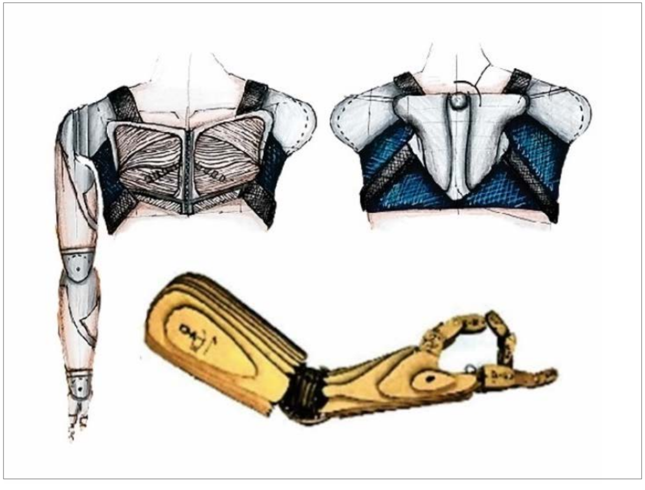

Figure 1. Design conceptualization

5.1. Agile Prototyping and Testing

Feedback from the interdisciplinary team and the subject of study allows choosing the option of greater feasibility through the sketches. After this process, the detailed design is advanced, including dimension plans, exploded views, and visualization renders that continue with the development of the functional prototype.

The focus on the subject of study includes strategic decisions about materializing the printed parts in order from the hands to the socket or torso. In this way, it seeks to facilitate a process of progressive adaptation of the person with disabilities, giving space to possible psychological interventions with the use of technology and self-image management [29].

In terms of design and materials, the open socket is designed as a vest with a hexagonal pattern on the chest that favors the optimization of the material. Thermoplastic Polyurethane (TPU) is chosen, which also allows ventilation of the body, minimizing sweating, and offering flexibility due to its thermoplastic rubber properties, consistent with the expansion during breathing. Complementarily, an adjustable frontal closure employs lashing straps secured with velcro.

A TPU area is also used for the back. In this case, due to the characteristics of the double amputation, it is conceived as a smooth surface without hollows. This offers structural strength to support the weight of the two prosthetic arms while protecting the wiring system that would be exposed with a mesh design.

The rest of the socket, as the pieces that have direct contact with the upper amputations, is defined in PLA to facilitate the fit with the arms of the same material. The PLA applied to the shell provides impact resistance and protects sensitive body areas, such as the stumps. The design described above is displayed in Figure 2.

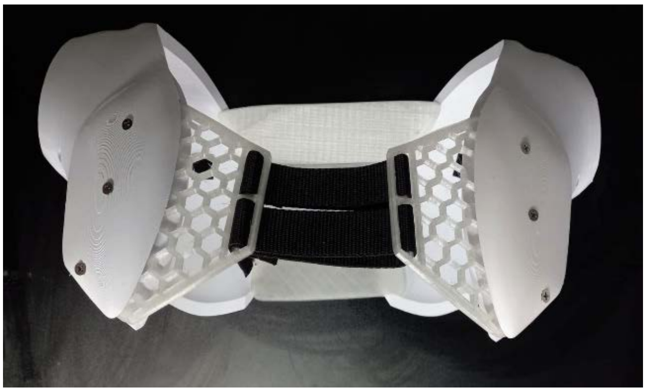

Figure 2. Design and photography of the 3D-printed socket

Regarding the union systems between the socket and the arms, the joint is designed based on the vertical movement of the shoulders by flexion and extension. This allows the development of a more significant number of essential functions compared to those achieved with abduction movements.

The design of the arms is configured with gyroid infill, which, due to its labyrinthine structural pattern and symmetry, provides high resistance against multidirectional external forces and allows ventilation flow, minimizing overheating of internal electronic components; Likewise, it supposes a saving of material by reducing printing times and weight of the parts. For the pieces that make up the arm, the padding is modified depending on their size, resistance, total weight, and ease of movement.

From an experimentation process through printing tests with the materials, filling percentages of 0, 5, 10, 15, 20, 30, and 50 are explored, as indicated in Figure 3. In relation to the above mentioned process, the higher the percentage, the greater the compaction of the chosen gyroid pattern, which provides greater resistance while increasing weights and costs due to an increase in the use of material and more significant power requirement of the servomotors.

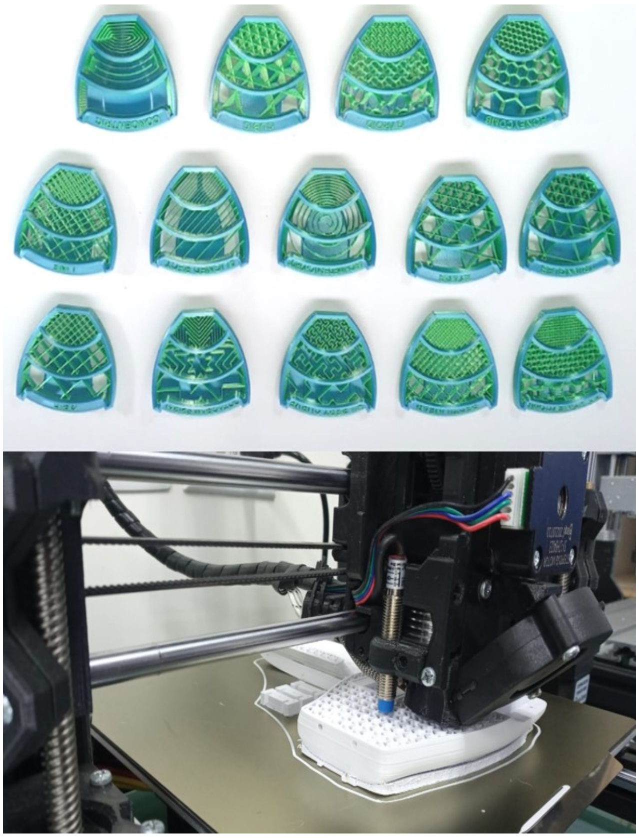

Figure 3. Infill exploration with additive technology

Consistent with previous investigations, the part specifications for the printing process are listed in Table 1.

Table 1. Data on materials and fillings by general parts and for the printing process

Parts	Type of material	Material quantity (grams)	% Infill gyroid
Socket			
Left rear	PLA	273	30%
Right rear	PLA	273	30%
Left front	PLA	263	30%
Right front	PLA	263	30%
chest union	TPU	33	15%
back union	TPU	92	10%
Arm 1			
Lower right	PLA	196	20%
Lower left	PLA	217	20%
Upper right	PLA	306	20%
Top left	PLA	155	20%
Shoulder rotation axes	PLA	25	50%
Forearm 1			
A couple of motors	PLA	0,4	10%
Bottom left and right	PLA	284	20%
Top left and right	PLA	227	20%
Closing cap and shaft	PLA	3	30%
Shaft joints	PLA	23	40%
Hand 1			
Fingers	PLA	9	50%
Palm	PLA	88	30%
Palm cap	PLA	24	30%
Phalanxes	PLA	1	50%
H finger connectors	TPU	0,4	0%

The Blender program is used for digital modeling due to its multiplatform advantage and open-source development model. The UltiMaker CURA printing program is added due to its easy interface handling and high compatibility with the national 3D printers available in the PUCE brand Minka S-Pro based on Prusa. The overall design was conceived by adjusting the parts to the printers available at the university with maximum print dimensions of 22cm x 22cm x 28cm in height.

The 45 pieces that make up the design, as indicated in Figure 4, were grouped into the areas of the shoulder, arm, upper and lower forearm, palm, and finally, the fingers. The latter is moved through polyamide ropes arranged in internal guide channels. The interphalangeal joints in fingers are attached with designed connectors type H in TPU, facilitating extension and flexion movements. A 1mm deep hole in the tips of the fingers and the phalanges are conceived to place silicone rubber that enables adherence for effective grips.

Concerning the subject of study and with the focus of humanizing the technology-human bond, their assistance to the PUCE 3D printing laboratories is coordinated so that they can participate in the printing processes of the prostheses, manipulate the parts and learn about the technology and prototyping times.

It seeks to sensitize to improve adaptation processes by creating links between the prosthetic object, the context, and the human being and create an environment of greater trust for exchanging criteria that reinforce verifications and decision-making. The instance of participation is coordinated during the creation of the hand since, as an executive instrument of activities, languages, and behaviors; it favors emotional and sensory ties.

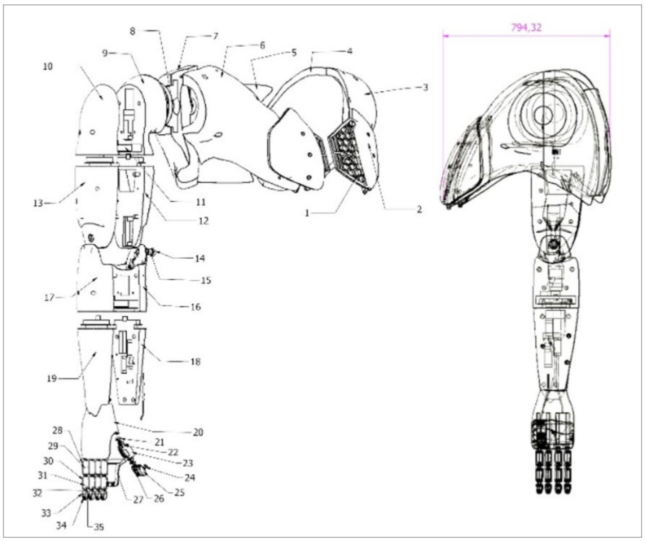

Figure 4. Detailed plans of the parts drawn in Autodesk Inventor

Regarding the electronic components and operating mechanisms displayed in Figure 5, 3 micro servomotors are established, four servo standards of 12kg of torque and 180° rotation amplitude, and individual potentiometers for external control of motor movement connected to an Arduino ADK 6-pin Pulse Width Modulation (PWN) powered by an external 5 volts 10-amp source. For electronic verification, the Fritzing online program was used, which allowed us to represent the circuits and simulate the connections between motors, validating the functionality of the design in a digital environment that helps optimize costs before physical prototyping.

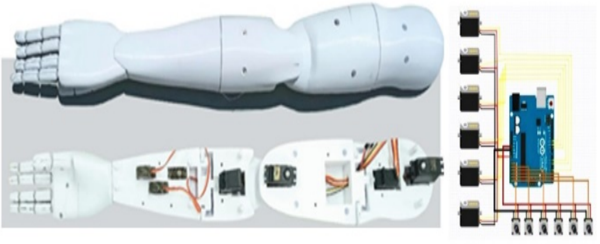

Figure 5. Simulation in Fritzing (right) and location of electronic components in the arm (left)

After the complete assembly of 3D printed parts and the placement of internal circuits, the verification phase proceeds, where the results are validated, and minimal details are modified according to the interactions with the design. First, observational tests were carried out to verify how and with what sequence of use the exoprosthesis was attached to the body. In this same instance, the dimensions are validated, confirming possible friction, thickness, the total weight of the prosthesis, and custom fit. The result yielded two valid placement options, by upper lace or as a vest. Between the skin and the socket is a custom-made sleeve made of a neoprene fabric that prevents chafing with the stumps and absorbs sweat that negatively influences the useful life of the prosthesis. According to the subject's indications, placement as a vest is preferred since it offers greater autonomy. In this sense, the conception of an assembly from the wall at the height of the back station is projected.

Secondly, the functionality of the developed prototype is verified, as indicated in Figure 6, for the fulfillment of the basic needs. Three videos are made in the frontal, lateral, and close-up positions. They allow recording the angular ranges achieved for movements centered on the joints, as well as the externally controlled grips of 1) pincer, 2) grip and displacement, and 3) cylindrical grip; these were validated with various objects, including cutlery, mouse, and a glass.

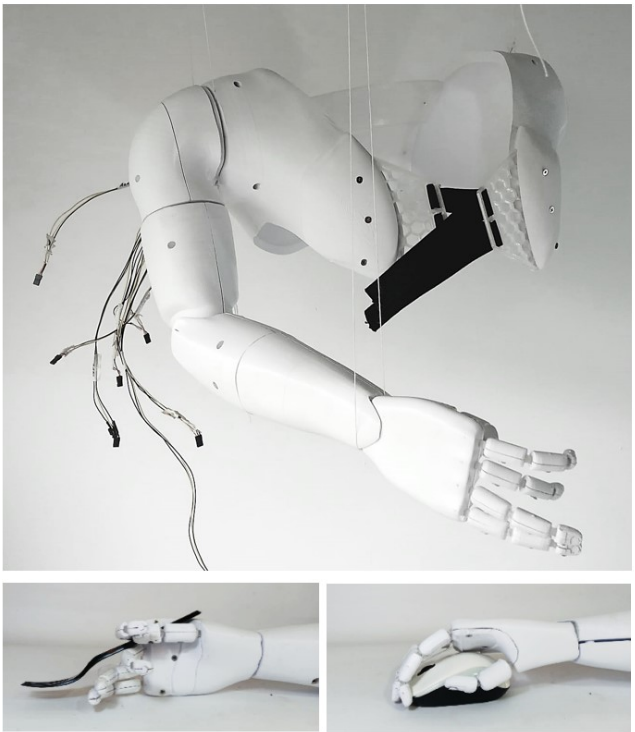

Figure 6. Functional prototype and grip validations according to basic needs

For closure, a meeting is arranged with the study's subject to determine their criteria of the results, which allows for establishing improvements in the prototype for a later phase of the project's continuation. High motivation for the design is recorded from the meeting, and it is desired that the material is not white but that the color adjusts to the skin tones of the potential user. Satisfaction is found in achieving autonomy due to the ease of use when putting on the product. The total weight of the exoprosthesis, including the socket, is of concern, although it does not exceed the actual weight of the arms of a non-disabled person. However, the percentages of fillers can be reviewed, follow-up for adaptation in this regard, and placement of the parts gradually. As for the fingers, it is defined as very important to maintain the rubber coatings to achieve not only instantaneous grips but also that these remain stable for as long as each specific need demands.

6. Conclusion

Some of the most relevant findings result from academic experience. In research terms, there is a limitation in the creation of personalized exoprostheses for people with disabilities, at least due to the absence of upper limbs in Ecuador. This provides a space for debate and practical action regarding social and regulatory interventions on the inclusion of minorities in the country. At the same time, it makes the academy responsible for the dissemination of knowledge to activate national and international collaboration networks, promoting the development of new technologies that are efficient in terms of costs and that, through interdisciplinary practices, create the paths for the future by promoting more creative and innovative solutions that lead to discoveries.

Equally important has been a dedicated and ongoing process of experimenting with materials, exploring their unique characteristics, and harnessing their potential in tandem with the latest technological advancements in 3D printing. Progress is made in an economically accessible device, and a functionally effective solution is offered according to the specific needs of patients with complex upper amputations in health and in terms of mobility, structure, comfort, and self-image improvement. The design process and personalized manufacturing are accelerated, which gives hope and creates new alternatives for particular cases that traditional medicine found limiting.

Finally, holism in the project is recognized as an essential process for designing and developing the exoprosthesis.

It provides a structured and systematic approach of creative synergy in constant feedback to address tough challenges from various fields of action. Likewise, the product designer's role is validated as an actor who projects and instrumentalizes the different interdisciplinary information and relates it, formalizing it into an aesthetic and functional assistance product.

On the collaborative approach it is important to highlight the intellectual and interdisciplinary effort focused on the personalized service of a unique subject with disabilities. In this sense, the assigned resources are not arranged based on the user's purchasing power or from a product business approach but instead are determined from the needs and based on the value of a human being without distinctions.

The fact that technology facilitates the support of projects with humanized, inclusive and global visions changes the paradigm from thinking only about consumer products to thinking about assistance products that bring richness to life. In this case, one person consumes, and several provide from their various fields of action in fusion.

Product design, psychology, and electronic engineering are not the only areas that can be integrated and provide value in similar projects; however, they show that in addition to knowledge, the will directs the actions, creating confidence in the work from the academy and with a system of collaborative actors where hierarchies between researchers, academics and students are dissolved.

Regarding future implications, the study has accelerated the research process and improvement of training quality at the PUCE. In addition, it opens spaces for permanent collaboration between product design and complementary disciplines for the conception of new health applications. In addition to psychology and engineering and to face new challenges, the areas of biology and medicine are added. In this sense, it is proposed to strengthen exploration with biomaterials and direct the focus of projects also towards rehabilitation.

The results show that design students in plural work teams enhance their abilities to respond to global problems. This guides the university curriculum towards updating programs where technology, strategic management, and communication are vital to contributing significantly to society and professionalization.

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References:

[1]. Trujillo Vanegas, C., González Vargas, E., & William, S. B. (2022). *Educación para la inclusión: aportes desde la investigación*. Medellín, Colombia.: Corporación Universitaria Remington y Universidad Surcolombiana.

[2]. Ministerio de Salud Pública. (2022). *Consejo Nacional para la Igualdad de Discapacidades*. Gobierno de la Republica del Ecuador. Retrieved from: https://www.consejodiscapacidades.gob.ec/estadisticas-de-discapacidad/ [accessed: 07 May 2023].

[3]. El Universo. (2018). *Acceso a prótesis mejora en Ecuador, pero aún hay deficiencias*. El Universo. Retrieved from: https://www.eluniverso.com/noticias/2018/10/28/nota/7016252/acceso-protesis-mejora-ecuador-aun-hay-deficiencias/ [accessed: 15 May 2023].

[4]. UNE Normalización Española. (2023). *Productos de apoyo para personas con discapacidad (ISO 9999:2023)*. UNE Normalización Española. Retrieved from: https://www.une.org/encuentra-tu-norma/busca-tu-norma/norma?c=norma-une-en-iso-9999-2023-n0070970 [accessed: 18 May 2023].

[5]. Naciones Unidas. (2023). *Objetivos de Desarrollo Sostenible | Programa De Las Naciones Unidas Para El Desarrollo*. Retrieved from: https://www.undp.org/es/sustainable-development-goals [accessed: 07 June 2023].

[6]. Pontificia Universidad Católica del Ecuador. (2021). *PUCE Proyecto Académico. Magis 2021-2025*. Quito: PUCE. Retrieved from: https://www.puce.edu.ec/intranet/magis/#proyecto [accessed: 11 June 2023].

[7]. Pei, M. E. (2010). *ID Cards*. England: Loughborough University & IDSA. Retrieved from: https://www.idsa.org/wp-content/uploads/IDSA%20iD%20Cards.pdf [accessed: 11 June 2023].

[8]. Wohlers Associates. (2022). *Wohlers Report 2022. 3D Printing and Additive Manufacturing Global State of Industry*. Washington DC.: Wohlers Associates & ASTM International.

[9]. Neagu, A. (2023). 3D and 4D printing of assistive technology. In *Towards 4D Bioprintin*, 69-89. USA: Elsevier.

[10]. Varsavas, S. D., Riemelmoser, F., Arbeiter, D., & Faller, L.-M. (2022). A review of parameters affecting the success of lower-limb prosthetic socket and liners and implementation of 3D printing technologies. *Materials Today: Proceedings, 70*, 425-430. https://doi.org/https://doi.org/10.1016/j.matpr.2022.09.280

[11]. Barrios-Muriel, J., Romero-Sánchez, F., Alonso-Sánchez, F. J., & Salgado, D. R. (2020). Advances in orthotic and prosthetic manufacturing: A technology review. *Materials*, *13*(2), 295.

[12]. Agency for Healthcare Research and Quality (AHRQ). (2023). *Department of Health and Human Services of United States*. Retrieved from: https://www.ahrq.gov/ [accessed: 20 June 2023].

[13]. Solís, C. L. B., Arrioja, S. G., & Manzano, A. O. (2005). Índice de Barthel (IB): Un instrumento esencial para la evaluación funcional y la rehabilitación. *Plasticidad y restauración neurológica*, *4*, 81-85.

[14]. Repko, A. F., Szostak, R., & Buchberger, M. P. (2019). *Introduction to Interdisciplinary Studies* (3rd edition). USA: SAGE Publications, Inc.

[15]. Ambrose, D. (2017). Large-Scale Interdisciplinary Design Thinking for Dealing with Twenty-First Century Problems and Opportunities. En Creativity, Design Thinking and Interdisciplinarity. *Creativity in the Twenty First Century,* 35-52. Singapore: Springer.

[16]. Muratovski, G. (2017). Towards Evidence-Based Research and Cross-Disciplinary Design Practice. En *Creativity, Design Thinking and Interdisciplinarity*, 3-15. Singapore: Springer.

[17]. García, J. (2020). Multi, inter y transdisciplinariedad. *Problema anuario de filosofía y teoría del derecho,* (13), 347-357.

[18]. Maldonado- Garcés, V. et al. (2020). Characterization and Socio-Cognitive Needs of People with Intellectual Disabilities. En I. C. AHFE, Advances in Intelligent Systems and Computing, *1205,* 376–381. Estados Unidos: Springer, Cham. Doi: 10.1007/978-3-030-50838-8_51

[19]. Reyes, L., Mendoza, G., & Rodríguez, J. C. (2022). Enfoques de diseño de tecnología para la salud en la academia: estudio comparativo. *Ava Cient, 13*(2), 101-112.

[20]. Norman, D. A. (n.d). *Humanity-Centered Design*. Interaction Design Foundation. Retrieved from: https://www.interaction-design.org/literature/topics/humanity-centered-design [accessed: 20 June 2023].

[21]. Rivera, Y., & Turizo, L. (2014). ABP (Aprendizaje Basado en Problemas) para la enseñanza y el desarrollo de proyectos tecnológicos interdisciplinares basados en arduino. *Encuentro internacional de educación en ingenieria ACUI14*.

[22]. Vergara, M., Díaz, M., Echeverría, Rivas, F., & Restrepo, M. (2017). *Diseño de dispositivos para rehabilitación y órtesis.* Ecuador: Centro de Publicaciones PUCESI. Retrieved from: https://edipuce.edu.ec/diseno-de-dispositivos-para-rehabilitacion-y-ortesis/ [accessed: 21 June 2023].

[23]. Homo medicus. (2022). Homo medicus - Conocimiento médico en evolución.... Retrieved from: https://homomedicus.com/ [accessed: 20 July 2023].

[24]. Ingenieria biomedica. (2014). *Johns Hopkins University prueba el prototipo de prótesis de doble brazo completo más sofisticado has.* Ingenieria biomédica. Retrieved from: https://www.ingenieriabiomedica.org/post/2014/12/18/johns-hopkins-university-prueba-el-prototipo-de-pr%C3%B3tesis-de-doble-brazo-completo-m%C3%A1s-sofi [accessed: 21 June 2023].

[25]. Hussein, M. E., & Brooker, G. (2014). *3D printed myoelectric prosthetic arm*. [Thesis, University of Sydney]. Sydney, Australia: University of Sydney.

[26]. Pérez, K. (2023). *Diseño y fabricación mediante impresión 3D de una prótesis mecánica de brazo.* [Bachelor's thesis, Universitat Politècnica de Catalunya] Barcelona, España.

[27]. Puca, D. G. (2022). *Prototipo funcional por método de manufactura aditiva FMD de una prótesis de mano articulado con sensor muscular EMG*. [Thesis, Universidad Internacional SEK]. Quito, Ecuador.

[28]. Lago, S. L. (2021). *Vademécum de métodos de diseño*. España: Ed. Experimenta.

[29]. García, K. J. (2017). Ajuste psicosocial en pacientes amputados: la psicología en el contexto sanitario. *Revista Cúpula, 31*(2), 8-43.