Additive Manufacturing of a Monomaterial TPU Exoskeleton for Rheumatoid Arthritis: Fabrication Strategy and Preliminary Evaluation

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ABSTRACT

[Rheumatoid arthritis (RA) progressively impairs hand mobility and limits daily activities, and commercial orthoses are often rigid, poorly fitted, or costly. Previous work proposed a customized monomaterial thermoplastic polyurethane (TPU) exoesqueleton with a functional stiffness gradient and validated its geometry computationally. However, its physical fabrication had not been reported. This study describes the additive manufacturing of that orthosis and documents the fabrication process and its outcomes. The device was printed in TPU [90A] using fused deposition modeling. Printing parameters, including nozzle temperature, speed, layer height, and region-specific infill, were defined to produce stiffer support zones and more flexible movement zones within a single material. The printed prototype was characterized by its mass, print time, material use, and dimensional deviation relative to the CAD (Solidworks) model, and it was inspected for fit, flexibility, and ease of donning and doffing. The prototype was obtained in 4 hours with a mass of 30 g, and the main printing difficulties were [stringing, jams, adhesion] and were addressed by [adjustments]. Preliminary observations indicated [fit and flexibility findings]. The prototype has not been tested with RA patients, so functional and clinical effectiveness remain unverified. These results show that a monomaterial TPU orthosis can be fabricated with accessible FDM technology and provide printing guidelines for future usability and clinical evaluation.]

Keywords: Rheumatoid arthritis, exoesqueleton, Thermoplastic polyurethane (TPU), Additive manufacturing, Monomaterial design

INTRODUCTION

[Rheumatoid Arthritis (RA) is a chronic, systemic autoimmune disease characterized by persistent synovial inflammation that triggers progressive destruction of articular cartilage and severe structural deformities, particularly affecting hand joints (Gamero García, 2018). In Mexico, RA is estimated to affect between 0.5% and 1.0% of the adult population, with a higher prevalence among women of working age. This clinical impact translates into a drastic loss of manual biomechanical function (grasping, pinch grip, and fine manipulation), compromising independence in Activities of Daily Living (ADLs). Indeed, within the national context, physical mobility alterations represent the factor with the highest impact on patients' lifestyles, reaching an influence of 85.5% (Bernal-González et al., 2020).

Despite the availability of traditional pharmacological and therapeutic interventions, conventional commercial orthotic devices frequently exhibit critical shortcomings, such as excessive stiffness, poor anatomical fit, thermal discomfort, and low long-term compliance rates (Chhikara et al., 2023; Gilanlıoğulları & Soyer, 2025). In response to these limitations, rehabilitation engineering and industrial design have converged toward additive manufacturing and the application of flexible elastomers.

In the prior phase of this research project, a personalized Thermoplastic Polyurethane (TPU 90A) orthosis was designed and computationally validated through a monomaterial functionally graded approach. Finite Element

Analysis (FEA) simulations demonstrated the structural effectiveness of the device, achieving a maximum von Mises stress of 5.855 MPa under operational loads of 50 N, which ensured a safety factor greater than 3.4 relative to the elastic limit of TPU 90A (20 MPa). However, that work was constrained to numerical model validation and the linear elastic behavior of TPU 90A within a virtual environment.

Therefore, the present study is justified by the imperative need to extend the biomechanical experimentation and material characterization phase, evaluating alternative polymers and structural combinations to optimize the trade-off between mechanical support and tactile ergonomic comfort (Polygerinos et al., 2017). To rigorously ground this exploration, the SALSA methodology (Search, Appraisal, Synthesis, Analysis) will be employed, enabling an exhaustive, systematic, and critical review of recent scientific literature (Grant & Booth, 2009; Page et al., 2021) regarding 3D-printed elastomers, bio-based filaments, and composite structures applied to medical devices.

Through the SALSA framework, the physical and mechanical properties of various alternatives will be analyzed in a structured manner against conventional rigid polymers such as PLA, which exhibits high stiffness (~80D) but low impact resistance and limited anatomical adaptability. Furthermore, the performance of thermoplastic elastomers under continuous use will be evaluated, taking into account phenomena such as mechanical fatigue and hysteresis under cyclic loading (Lima & Silva, 2022).

Likewise, it is essential to experimentally contrast rigid supporting materials (such as PLA for biomechanical cores) with soft lower Shore hardness interfaces (such as TPU 60A–85A or biodegradable and biocompatible materials) to address the diversity of clinical stages in RA (Singh et al., 2020; Xiloyannis et al., 2022). Deepening the understanding of the thermomechanical characterization, durability, elongation at break, and non-linear behavior of these polymers will allow to:

Ensure the structural durability of the exoskeleton during repetitive flexion and extension cycles characteristic of precision pinch grips (Valero-Cuevas, 2020).

Prevent pressure points and excessive friction on atrophic skin or acutely inflamed joints (Polygerinos et al., 2017).

Evaluate the use of biocompatible and sustainable materials that facilitate low-cost distributed manufacturing within the Mexican public healthcare system (Granados-García & Ávila-Burgos, 2021; Moya-Jiménez & Magal-Royo, 2020).

Combining the SALSA methodology with experimental testing will provide the scientific backing and physical evidence required to consolidate a hand orthotic/exoskeleton device that is not only structurally viable in simulations, but also optimizes its material properties to offer maximum functionality, lightness, and biomechanical comfort in patients' daily use.]

LITERATURE REVIEW

Rheumatoid arthritis, hand function and the need for assistive devices

[Rheumatoid arthritis (RA) is a chronic systemic disease in which persistent synovial inflammation can progress to cartilage destruction and joint deformity, including in the upper limbs (Gamero García, 2018). In Mexico, its expected burden has been projected through 2040 (Mendoza-Pinto et al., 2026), and physical mobility has been reported as the most affected dimension of patients' lifestyle, with an impact of 85.5% (Bernal-González et al., 2020). Hand function is closely linked to activity performance (Kılıc et al., 2018). Patients' own descriptions of activity limitations (Yang et al., 2025) and the functional dependence in basic activities of daily living and its family repercussions (Avila Martínez et al., 2024) show why preserving hand use matters. Health-related quality of life in RA has also been widely studied (Franco-Aguirre & Cardona-Arias, 2015). These studies establish the clinical need and the main design variables, but they do not specify how a wearable device should be built..]

Soft and passive approaches

[Soft devices are an alternative to rigid mechanisms. Polygerinos et al. (2017) reviewed intrinsically soft devices, and Xiloyannis et al. (2022) reviewed soft upper-limb exoskeletons, contrasting passive and active approaches. Passive soft designs avoid actuators and control electronics, which reduces complexity and cost, but their application to RA remains little documented.]

Additive manufacturing and TPU

[Additive manufacturing has been used to customize orthoses for arthritic conditions (Moya-Jiménez & Magal-Royo, 2020), and material choice is central for devices in contact with the body (Singh et al., 2020). Thermoplastic polyurethane (TPU) is attractive for medical and wearable uses because of its lower stiffness compared with PLA and ABS, but its mechanical response in fused filament fabrication depends on parameters such as layer height and nozzle temperature (Kechagias et al., 2021). Kaplan et al. (2025) examined a TPU wrist-hand orthosis printed by FDM, testing combinations of layer thickness, infill pattern and nozzle temperature and predicting hardness and surface roughness. These studies show the potential of TPU, but they focus on process parameters or specimens rather than on the full fabrication of an RA hand device.]

User-centered design

[User-centered design (UCD) and the integration of patient and therapist feedback are recognized strategies for the acceptance of wearable assistive technologies (Interrante et al., 2021), and the ExoGlove evaluation applied them to RA (Moya-Jiménez et al., 2025).]

Research gap

[The literature shows (i) a clear clinical need in RA, (ii) many rigid or actuated hand exoskeletons, mostly developed for paralysis or rehabilitation settings, and (iii) growing interest in TPU for customized orthoses. However, reports that describe the actual fabrication of a monomaterial TPU hand exoskeleton for RA, with its printing strategy, results and difficulties, remain scarce. This study addresses that gap by documenting the additive manufacturing of such a device and its preliminary evaluation.]

METHODOLOGY

Study design

[This study followed a sequential design–fabrication workflow organized in five phases: (1) a SALSA-based literature review, (2) definition of design requirements under User-Centered Design (UCD) principles (International Organization for Standardization [ISO], 2019), (3) parametric CAD (Solidworks) design and computational validation, (4) additive manufacturing of the prototype, and (5) preliminary evaluation of the printed device. Phases 1 to 3 were reported previously (Lugo Islas et al., 2026) and are summarized here to give context. Phases 4 and 5 constitute the contribution of this study.]

Phase 1. Literature review (SALSA)

[The Search, Appraisal, Synthesis and Analysis (SALSA) framework (Grant & Booth, 2009) was used to structure the evidence base. The search was carried out in [databases] between [dates] using combinations of terms related to rheumatoid arthritis, hand orthoses and exoskeletons, additive manufacturing and thermoplastic polyurethane (TPU) [search strings]. [X] sources were retained, including journal articles, conference papers and theses in English and Spanish. During appraisal, each source was classified by type of activity (design, clinical, functional, material), technical complexity and relevance to the design, and sources with little relevance to the device (for example, work not focused on health) were excluded or used only as context. The retained evidence was synthesized thematically and analyzed to identify design criteria and gaps, as presented in the Literature Review.]

Table 1: [Data collection]

Author(s)	Year	Title	Objective	Results	Link
Moya, R., & Magal-Royo, T.	2019	Design and prototyping of a rehabilitation device for hand rheumatoid arthritis	Design and validation of a rehabilitation device focused on the hand of people with rheumatoid arthritis.	Initial prototyping aimed at hand rehabilitation to reduce motor limitation.	View Link
Lima dos Santos, S. P., & Cevallos Martínez, G. F.	2020	Promoting organ donation on the Twitter platform: An exploratory analysis in Ecuador / Design and prototyping with rapid prototyping techniques	Development and research through additive manufacturing and rapid prototyping techniques.	Application and integration of rapid manufacturing technologies for creating assistive devices.	View Link
Moya Jiménez, R. C.	2023	Systemic study of an exoskeletal structure for hand muscle atrophy rehabilitation in patients with rheumatoid arthritis	Structural, systemic, and biomechanical analysis of hand exoskeletons for muscle atrophy.	Detailed biomechanical modeling and systemic evaluation of exoskeletal structures for active rehabilitation.	View Link
Moya-Jiménez, R., Magal-Royo, T., & Ponce, D.	2020	Innovative digital technologies for hand exoskeleton design applied to chronic arthritis rehabilitation	Application of digital tools and technologies for innovation in hand exoskeletons.	Definition of digital workflows and technological innovations for exoskeleton customization.	View Link
Illescas Siavichay, M. J., & Morocho Guevara, K. J.	2025	Design and implementation of a hand orthosis for joint rehabilitation in patients with rheumatoid arthritis	Design and implement an electronically assisted rigid (ABS) hand orthosis for joint rehabilitation.	Clinical implementation of a functional electromechanical system with PID control for joint rehabilitation.	View Link
Bravo Cundar, B. S., Escobar Cerón, J. N., & López Chaves, J. D.	2025	Mixed reality application for joint protection during personal hygiene activities in early-stage rheumatoid arthritis patients	Develop an immersive mixed reality environment focused on joint prevention and protection in ADLs.	Demonstrated to be an effective educational tool for joint guidance and protection in early stages.	View Link
Bernal-González, A., Gallegos-Torres, R. M., & Peza-Cruz, G.	2020	Lifestyle profile and inflammatory activity in individuals with rheumatoid arthritis	Evaluate lifestyle and inflammatory activity level in Mexican patients with rheumatoid arthritis.	Physical mobility alterations were identified as the greatest impairment (85.5%) in patient lifestyle.	View Link
García García, S.	2024	Design and construction of a hand rehabilitation exoskeleton prototype	Design and build an exoskeleton prototype using rigid linkages for phalanx mobilization.	Successful mechanical prototype construction for clinical active rehabilitation therapy.	View Link
Franco-Aguirre, J. Q., & Cardona-Arias, J.	2015	Health-related quality of life in patients with rheumatoid arthritis:	Characterize scientific literature regarding quality of life in	Systematic review highlighting the sustained negative	View Link

		Characterization of studies published between 2003–2013	patients with rheumatoid arthritis.	impact of joint stiffness on patient autonomy.	
Gamero García, D.	2018 / 2022	Rheumatoid arthritis, epidemiology, pathophysiology, diagnostic criteria, and treatment	Compile and analyze the epidemiology, diagnosis, and pathophysiology of rheumatoid arthritis.	Clinical foundation evidencing how persistent synovial inflammation leads to progressive hand deformity.	View Link
Cuadrado Carmona, N., & Díez Buil, H.	2017	Effectiveness of physical therapy on hand symptoms in patients with rheumatoid arthritis	Evaluate the effectiveness of physical therapy interventions on hand joint symptoms.	Confirmation that continuous therapy reduces stiffness and preserves functional range of motion.	View Link
Nazari, V., Pouladian, M., Zheng, Y.-P., & Alam, M.	2021	A compact and lightweight rehabilitative exoskeleton to restore grasping functions for people with hand paralysis	Develop a compact, lightweight exoskeleton to restore grasping functions in hand paralysis.	Functional, lightweight device capable of restoring pinch force with integrated sensors.	View Link
Pani, D., Barabino, G., Dessì, A., Tradori, I., Piga, M., Mathieu, A., & Raffo, L.	2014	A device for local or remote monitoring of hand rehabilitation sessions for rheumatic patients	Develop a sensorized system for local and remote monitoring of hand rehabilitation sessions.	Effective implementation of tele-monitoring for force and joint range tracking during remote therapy.	View Link
Moya-Jiménez, R., Goyes-Balladares, A., Rivera-Valenzuela, M., & Magal-Royo, T.	2025	User-Centered Evaluation of the ARTH-Aid ExoGlove: Perspectives of Patients and Therapists in Rheumatoid Arthritis Rehabilitation	Evaluate acceptance and perception of the ARTH-Aid ExoGlove from patient and therapist perspectives.	High ergonomic and clinical usability ratings using User-Centered Design (UCD) methodology.	View Link
Moya Jiménez, R., Magal Royo, T., Ponce, D., Flores, M., & Caiza, M.	2020	Hand Exoskeleton Design for the Rehabilitation of Patients with Rheumatoid Arthritis	Design an assistive exoskeleton specifically tailored to joints affected by rheumatoid arthritis.	Validation of a mechanical design focused on guiding physiological hand flexo-extension patterns.	View Link
Fumagalli, L., Mossini, M., Nava, R., & Covarrubias, M.	2024	STRAHAND: Rehabilitation-Oriented Exoskeleton for the Hand	Develop the STRAHAND biomechanical structure focused on finger-oriented rehabilitation.	High-precision mechanism for guided reproduction of digital pinch movement.	View Link
Mendoza-Vázquez, G., Rocha-Muñoz, A. D., Guerra-Soto, A. J., et al.	2013	Rheumatoid arthritis and dyslipidemias	Analyze lipid alterations and systemic inflammation prevalence in patients with rheumatoid arthritis.	Identification of concomitant systemic inflammatory factors in arthritic patients.	View Link
Mendoza-Pinto, C., Munguía-Realpozo, P., Etchegaray-	2026	Projections of the Burden of Rheumatoid Arthritis in Mexico from 2020–2040	Project the epidemiological and socioeconomic burden of rheumatoid arthritis	Predictive model showing sustained rise in prevalence, highlighting the need	View Link

Morales, I., et al.			in Mexico toward 2040.	for affordable technologies.	
Avila Martínez, L., Mada Duarte, D. A., & Tecuanhuey Tlahuel, H.	2024	Functional dependency for basic activities of daily living and its relation to family impact in patients with rheumatoid arthritis	Determine the degree of ADL dependency and its impact on family dynamics.	Shows a direct link between loss of manual function and increased level of family dependency.	View Link
Franco-Aguirre, J. Q., Cardona-Tapias, A. A., & Cardona-Arias, J. A.	2015	Disability in performing daily living activities in a group of individuals diagnosed with rheumatoid arthritis	Measure objective task limitations during daily activities in patients with rheumatoid arthritis.	Identification of critical impaired tasks (grasping, holding) essential for orthosis parameterization.	View Link
Yang, H., Khatiwada, A. P., Curtis, J. R., et al.	2025	Assessing activity limitations experienced by persons with rheumatoid arthritis to inform appropriate selection of patient-reported outcomes measures: a qualitative study	Qualitatively assess specific hand impairments to adapt outcome measurement instruments.	Detailed mapping of patient-perceived deficiencies to guide user-centered design metrics.	View Link
Kılıc, M. C., Calık, B. B., Cobankara, V., & Balkarlı, A.	2018	The Relationship Between Hand Function and Activity Performance in Patients with Rheumatoid Arthritis	Correlate hand biomechanical functional capacity with overall activity performance.	Confirmation of a strong correlation between digital pinch strength and patient independence.	View Link
Carriillo-Varela, J. A., & Hernáez-Hernández, J.	2023	Optimization of 3D printing parameters for thermoplastic polyurethane (TPU) structures in wearable medical devices	Optimize 3D printing parameters for flexible TPU structures in wearable medical devices.	Definition of optimal manufacturing parameters to achieve flexibility, durability, and low weight.	View Link
Valero-Cuevas, F. J.	2020	Fundamentals of Neuromechanics and Control of the Human Hand	Analyze kinematics, force distribution, and neuromechanical control of the digital pinch.	Theoretical and mathematical foundation of phalanx behavior during manual grasp.	View Link
Salgado-Bustamante, M., & Pérez-Rodríguez, G.	2021	Psychological well-being and social adaptation in young adults diagnosed with rheumatoid arthritis	Evaluate psychological health and social adaptation during early disease stages.	Evidence supporting the necessity of comfort and low stigmatization in assistive wearable design.	View Link
Polygerinos, P., Correll, N., Morin, S. A., et al.	2017	Soft robotics: Review of fluid-driven intrinsically soft devices	Review soft human-robot interfaces and pressure distribution on delicate tissue.	Demonstrates how soft robotics prevents stress concentrations and protects inflamed joints.	View Link
Singh, S., Ramakrishna, S., & Singh, R.	2020	Material considerations in additive manufacturing of wearable and	Analyze compatibility, biocompatibility, and mechanical response of polymers in 3D printing.	Selection of polymers that minimize skin irritation and ensure long-term durability.	View Link

		implantable medical devices			
Xiloyannis, M., Antico, M., Cappello, L., & Masia, L.	2022	Soft exoskeletons for the upper limb: A review of recent advances in design and control	Compare passive vs. active mechanisms in soft exoskeleton design for upper limbs.	Establishes the ergonomic superiority and lightness of passive/soft structures over heavy active actuators.	View Link
Bedolla-Barajas, M., Morales-Cárdenas, A., & Robles-Vargas, C.	2019	Direct and indirect costs associated with the care of rheumatoid arthritis patients in a tertiary care hospital in Mexico	Quantify health care expenditures and disability-associated economic costs in Mexico.	Justifies the development of low-cost, locally manufactured orthotic solutions.	View Link
Interrante, V., Marceau, R., & Ries, B.	2021	User-centered design strategies for wearable assistive technologies	Establish iterative user-centered design methodologies for wearable assistive tech.	Design framework ensuring higher technology adoption rates and reduced device abandonment.	View Link
Moya-Jiménez, R., & Magal-Royo, T.	2020	Digital transformation in rehabilitation engineering: Custom 3D-printed orthoses for chronic arthritic pathologies	Apply digital transformation for custom 3D-printed orthosis manufacturing.	Efficient, low-cost custom manufacturing tailored to individual patient anatomy.	View Link
Lima, R. S., & Silva, D. C.	2022	Mechanical fatigue and hysteresis behavior of 3D-printed thermoplastic polyurethane under cyclic loading	Study thermomechanical response, fatigue, and hysteresis of TPU under cyclic loading.	Determines long-term behavior and resistance to plastic deformation of TPU under repeated flexion.	View Link
Granados-García, V., & Ávila-Burgos, L.	2021	Challenges in providing technologies for rehabilitation and disability in the Mexican health system	Analyze accessibility barriers and public policies regarding assistive technologies in Mexico.	Highlights public sector distribution challenges, emphasizing the development of independent national tech.	View Link

Phase 2. Design requirements

[Under UCD principles, requirements were derived from the literature on the needs and limitations of people with RA. They included anatomical customization, a monomaterial TPU construction with regional stiffness variation, low weight, ease of donning and doffing, and compatibility with fused deposition modeling (FDM) (Lugo Islas et al., 2026).]

Phase 3. CAD (Solidworks) design and computational validation

[A parametric model was developed in SolidWorks 2023 and analyzed by finite element analysis (FEA) assuming TPU 90A as a linear elastic material. The simulation of a ring component under a 50 N static load reported a maximum von Mises stress of 5.855 MPa, below the material's elastic limit (Lugo Islas et al., 2026).]

Phase 4. Additive manufacturing

[The orthosis was fabricated by FDM on a [printer model, extruder type] using TPU filament [brand, Shore hardness, diameter]. The model was sliced in [software], and the printing parameters are listed in Table 1. The

gradient was produced by varying [infill density/pattern/wall thickness] between support zones ([X]%) and flexible zones ([X]%), without changing the base material.]

Table 2: [Printing parameters]

Parameter	Value
[Nozzler Diameter]	0.4 mm
[Nozzler Temperature]	220 °C
[Bed Temperature]	50 °C
[Print Speed]	25 mm/s
[Layer Height]	0.2 mm
[Infill (support/flexible zones)]	40% / 15% (Gyroid pattern)
[Retraction]	1.0 mm at 20 mm/s
[Orientation and support]	Flat on bed, no supports required

Phase 5. Preliminary evaluation

[The printed prototype was characterized by (a) mass, measured with a [scale, resolution]; (b) print time and filament consumption, as reported by the slicer and verified by [method]; (c) dimensional deviation between the CAD model and the printed part at [X] control dimensions, measured with a [caliper, resolution]; and (d) qualitative inspection of fit, flexibility of the gradient zones and ease of donning and doffing on [a hand model/anthropometric measurements]. Printing defects and the adjustments made between attempts were recorded. No human participants were involved, so no clinical or functional performance was assessed.]

RESULTS AND DISCUSSION

Computational validation of the assembled model

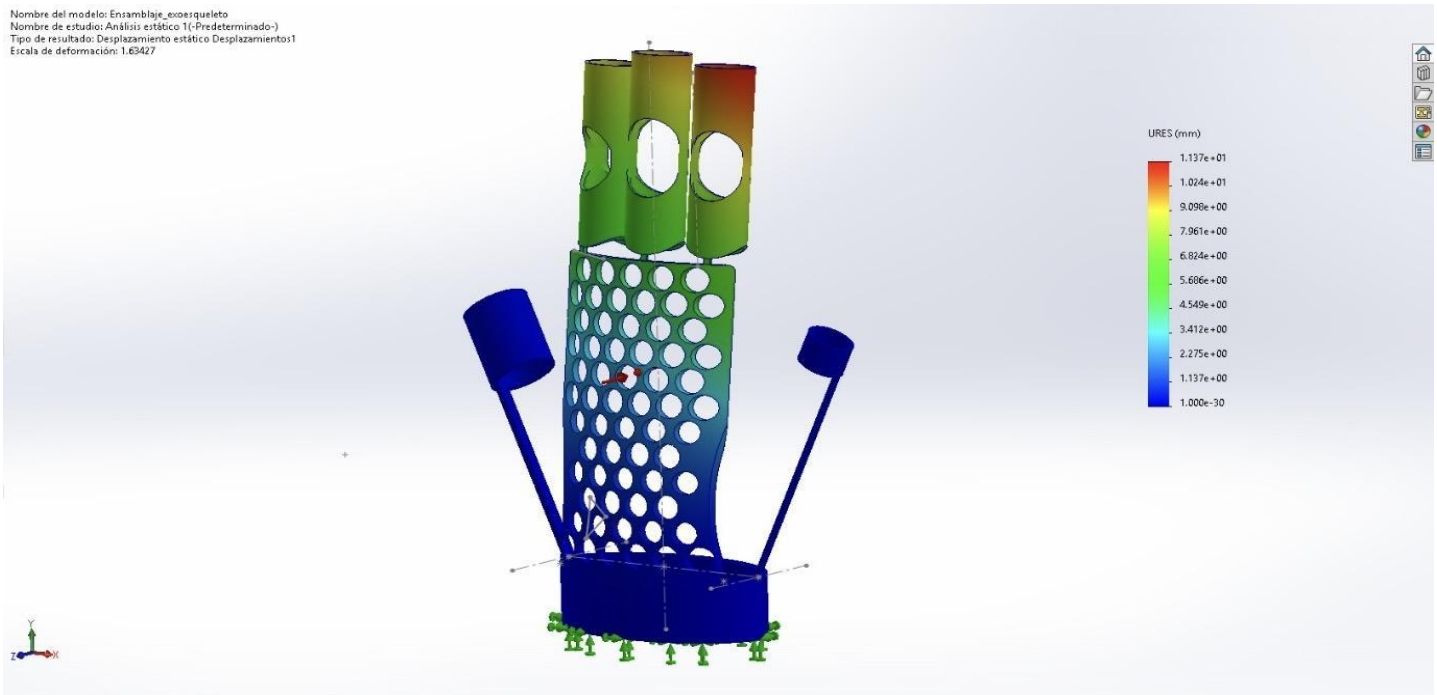


Figure 1: [Displacement plot from the initial static analysis of the hand exoskeleton, showing an implausibly high maximum displacement that indicates the need to review the simulation setup.]

Pressure test. A uniform pressure of 1,000 N/m² was applied to the assembled orthosis with a fixed base (Fig. [1]). The maximum von Mises stress was 1.10 MPa (5.5% of the 20 MPa yield strength of TPU 90A), the maximum resultant displacement was 11.37 mm at the fingertips, and the maximum equivalent strain was 2.9×10^{-2}. Stress remained low across the finger and joint regions, with local concentrations around the perforations and the base joints. The first static simulation of the hand exoskeleton revealed an extremely high displacement

magnitude, with a reported maximum of approximately 3.58 \times 10^6 mm. This value is physically implausible for the dimensions of the device and indicates that the numerical result cannot be interpreted as a realistic prediction of its structural behavior. Although the analysis was performed using a TPU-based design, the result may be associated with insufficient constraints, inadequate connections between components, incorrect material properties, or numerical instability. Therefore, this simulation was considered an unsuccessful validation attempt and highlights the need to verify the boundary conditions, assembly contacts, and material definition before drawing conclusions about the mechanical performance of the exoskeleton.

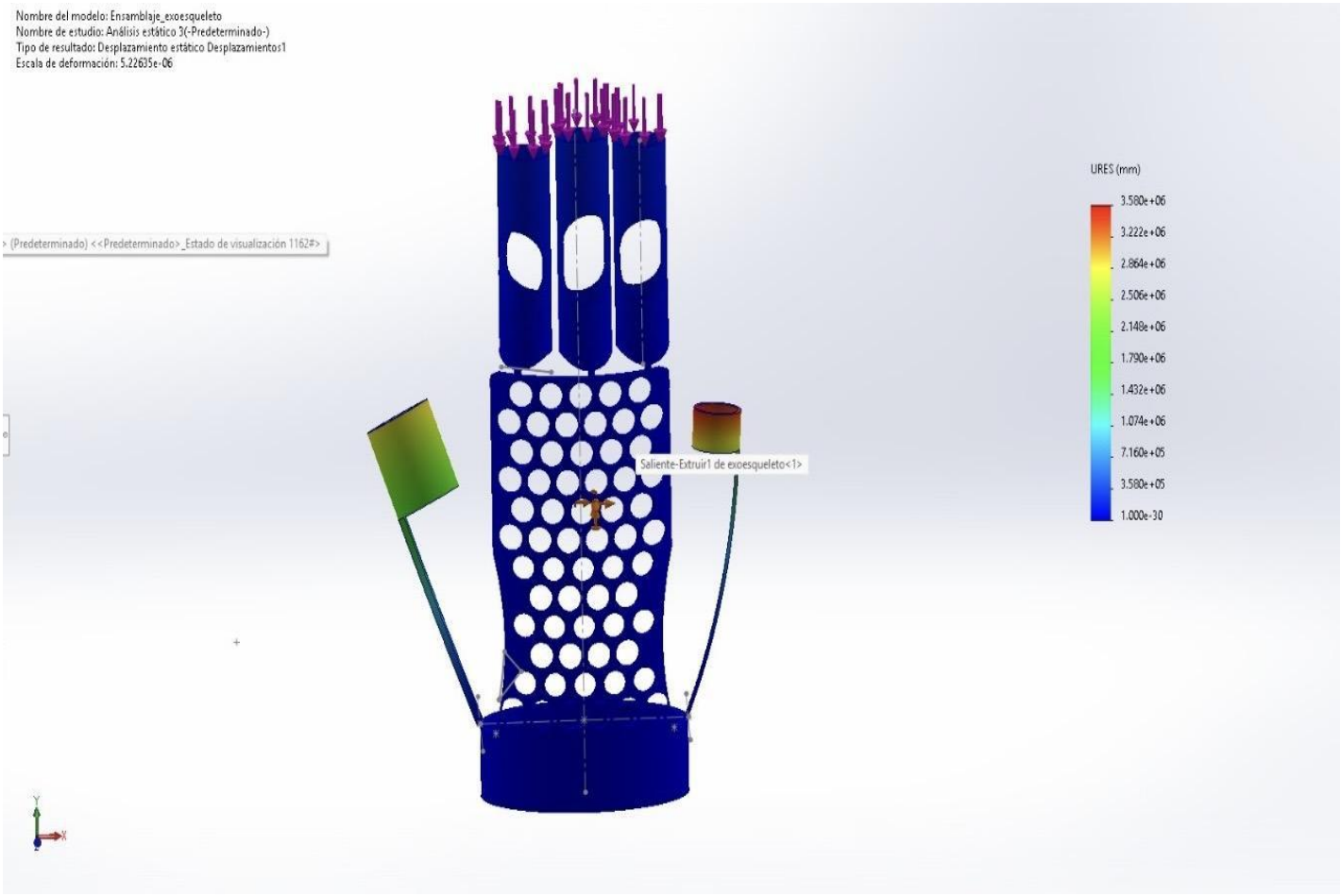


Figure 2: [Static structural analysis of the exoskeleton]

Safety factor. The von Mises criterion gave a minimum factor of safety of 1.8 [under the loading conditions of the safety-factor study: describe them], which is lower than the values previously reported for the isolated ring component (Lugo Islas et al., 2026), and indicates that [location of the minimum] is the critical region. To evaluate the mechanical behavior of the exoskeleton, a static analysis was performed using SolidWorks Simulation, considering the loading and boundary conditions defined in the model. Three main parameters were examined: von Mises equivalent stress, resultant displacement, and strain, which characterize the structural response of the design under the applied loads.

The von Mises equivalent stress distribution (Figure 2) showed a maximum reported value of 3.062\times10^{10} Pa, whereas the assigned yield strength of the material was 2.00\times10^7 Pa. The resultant displacement analysis (Figure 2b) reported a maximum value of 3.580\times10^6 mm, while the strain analysis (Figure 2c) reached a maximum value of 9.497\times10^2. These magnitudes exhibit substantial discrepancies with the values expected for a structural system of conventional dimensions.

Consequently, the results are considered preliminary and require verification of the assigned material properties, unit system, boundary conditions, component interactions, and magnitude and distribution of the applied loads. Once the model configuration has been validated and mesh convergence has been assessed, the factor of safety can be determined, enabling a more reliable evaluation of the exoskeleton's structural integrity.

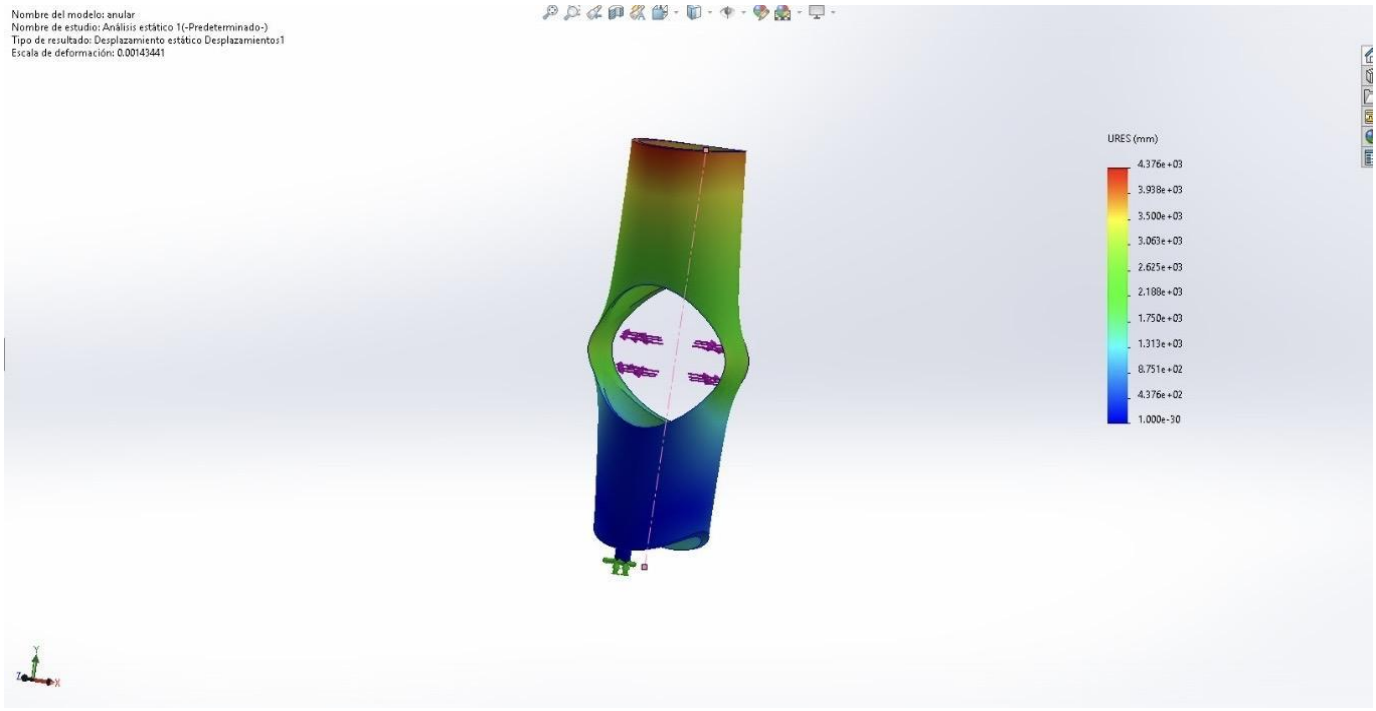


Figure 3: [Crushing load simulation.]

Crushing load. [The static analysis performed in SOLIDWORKS Simulation revealed an excessive deformation scenario in the evaluated component of the hand exoskeleton, conceptually designed using thermoplastic polyurethane (TPU). The resulting displacement distribution shows a maximum magnitude on the order of 4.376 \times 10^3 mm, according to the scale displayed in the figure. This value indicates that the numerical solution is not physically plausible for the component's dimensions and suggests that conditions beyond the validity range of the linear elastic model have been reached, or that insufficient restraints or connections may be present in the study configuration.

Due to the flexible and potentially nonlinear behavior of TPU, the results must be interpreted with caution, since the linear elastic model does not adequately represent large deformations or possible changes in the material's stiffness. Consequently, this simulation is not considered a structural validation of the design, but rather a diagnostic scenario highlighting the need to review the boundary conditions, component contacts, and assigned mechanical properties. For a more representative evaluation, it is recommended to verify the assembly configuration and subsequently perform a nonlinear analysis using TPU constitutive properties obtained from reliable experimental or technical sources.]

Printed prototype

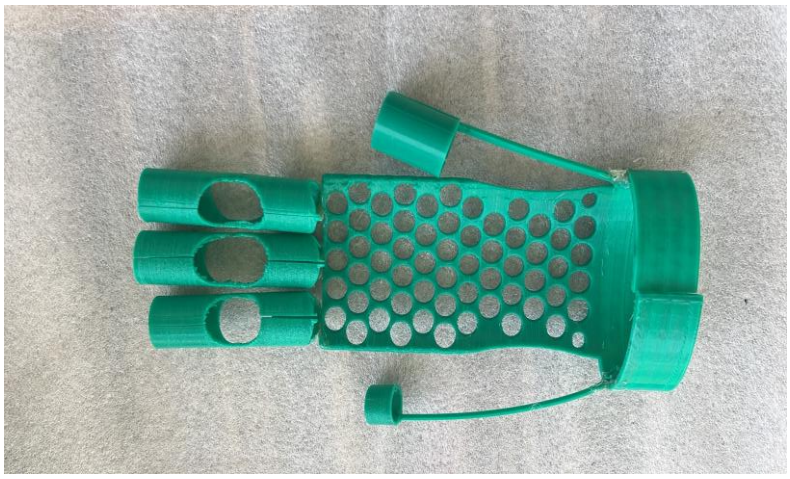


Figure 1: [Mass, print time, filament use, dimensional deviation, defects, fit and flexibility observations. Use the printing parameters from Table 1.]

CONCLUSION

[The static simulations provided an initial assessment of the mechanical response of the proposed hand exoskeleton. The first analysis produced an implausibly high displacement, indicating that the simulation setup required further verification. The second analysis yielded a maximum displacement of approximately 11.37 mm, allowing a more meaningful preliminary examination of the deformation distribution across the assembly. However, this value alone does not establish structural adequacy or functional suitability. Given the mechanical behavior of TPU 90A and the limitations of a linear elastic model under potentially large deformations, further verification of the material properties, boundary conditions, and component interactions is necessary. The factor of safety must also be evaluated using an appropriate failure criterion and valid material strength data before the structural performance of the proposed design can be assessed.]

ACKNOWLEDGEMENTS

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Ethical Approval

[This study involved a literature review, computer-aided design (CAD), and computational simulations of a hand exoskeleton intended to assist individuals with rheumatoid arthritis. No human participants or animals were involved in data collection or experimental procedures. Therefore, ethical approval was not required for this study.]

Conflict Of Interest

The authors declare that they have no conflict of interest.

Data Availability

[The data supporting the findings of this study, including the CAD (Solidworks) model, material specifications, simulation settings, and computational results, are available from the corresponding author upon reasonable request.]

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