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ADVANCED DESIGN METHODOLOGIES IN THE DEVELOPMENT OF HAND-WRIST-FOREARM ORTHOSIS

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Abstract: *Hand-Wrist-Forearm Orthosis come in a varied assortment of configurations and sizes to accomplish many different functions for support and immobilization. Athletic trainers, occupational therapists, physical therapists, orthopaedic doctors and emergency room and ambulance professional personnel often require specific hand splints to help their patients recover or rehab from injuries, or to assist in deformities or spasticity caused by certain health conditions. In many occasions, the patients are forced to use the Hand-Wrist-Forearm Orthosis during some time and due to their aesthetics, the patients aren't always comfortable in using them in every occasion. The main objective of this paper is to present novel design methodologies composed of advanced digital and physical manufacturing systems in order to produce good aesthetic light-weight Hand-Wrist-Forearm Orthosis. The steps are composed of 3D scanning the patients arm and then producing a digital model which is then optimised by using topological optimisation algorithms. After obtaining the optimised model, the physical model is then produced in an additive manufacturing system. The final result is an optimised light-weight Hand-Wrist-Forearm Orthosis with a design that the patient will feel comfortable in using in any occasion, even ceremonies, without compromising its objective functionality, helping them recover or rehab from injuries, or to assist in their deformities or spasticity.*

1 INTRODUCTION

An orthosis is an external component applied to the body in order to facilitate the execution of a task, to compensate for any deformities, reinforcing treatment of disease or even prevent diseases in the trunk and limbs. There is a great diversity of orthoses for the trunk, with different characteristics and different purposes which can be classified into Cervical Orthoses; Cervical Thoracic Orthoses; Cervico-Thoraco-Lumbo-Sacral Orthoses; Thoraco-Lumbo-Sacral Orthoses; Lumbo-Sacral Orthoses; Sacroiliac Orthoses and Hand-Wrist-Forearm Orthoses [1].

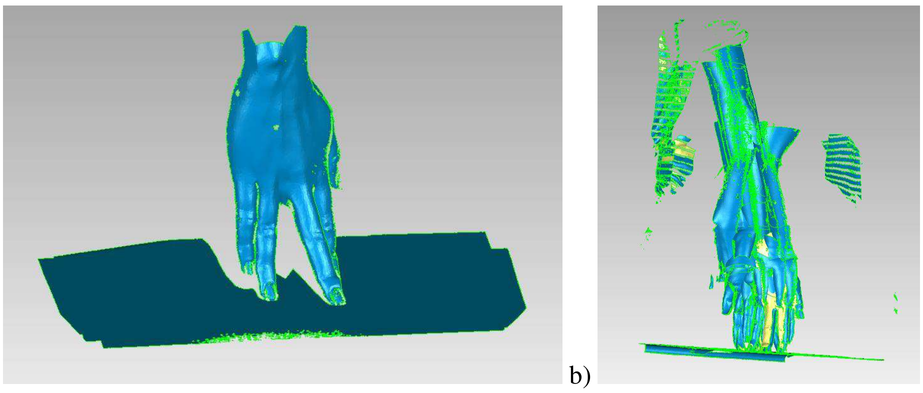
Hand-Wrist-Forearm Orthosis come in a varied assortment of configurations and sizes to accomplish many different functions for support and immobilization. Athletic trainers, occupational therapists, physical therapists, orthopaedic doctors and emergency room and ambulance professional personnel often require specific hand splints to help their patients recover or rehab from injuries, or to assist in deformities or spasticity caused by certain health conditions.

Comercial available orthoses are not personalized and all have a negative aesthetical impact during the time prescribed to use. Combining digital scanning and additive manufacturing systems into the production of this particular family of products increases both the functionality of the products as well as its aesthetics and appealing design towards the customers. The main objective of this paper is to present novel design methodologies composed of advanced digital and physical manufacturing systems in order to produce good aesthetic light-weight Hand-Wrist-Forearm Orthosis.

2 DESIGN METHODOLOGY

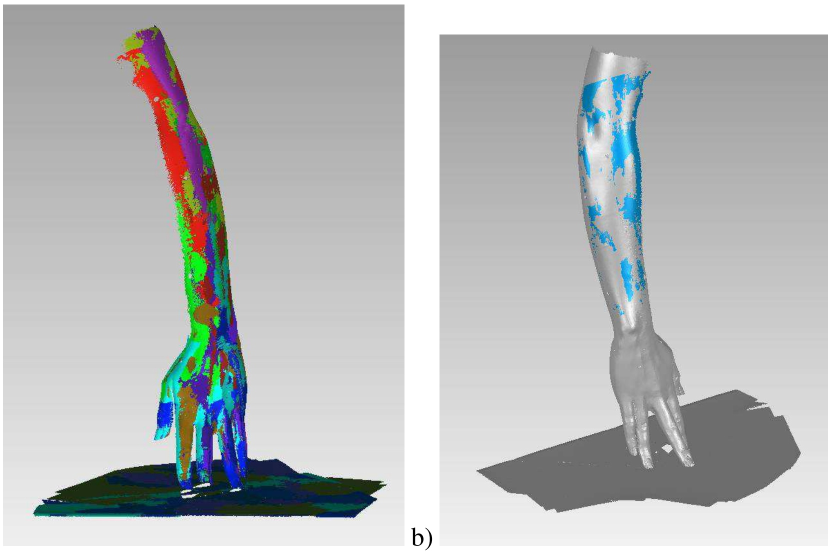
The first main step consists in obtaining the CAD data of the outer shape of the patient's hand-wrist-forearm in order to design the orthosis. In this case a 3D digital scanning system (GOM ATOS CORE) with a scanning volume of 300 cm^3, was used as illustrated in Figure 1. Figure 2.a illustrates one single scan shot and Figure 2.b illustrates all the obtained scan shots. Figure 3 illustrates the several point cloud matching steps. The scanned data is then processed (removal of noise data, filtering geometric data, filling of gaps and wholes) to create a corresponding surface CAD model.

Figure 1: 3D digital scanning procedure.



a) b)

Figure 2: a) Single scan shot and b) all obtained scan shots.



a) b)

Figure 3: a) Cloud matching of the several scan shots (each point cloud is represented with a different colour) b) Final point cloud matching.

Figure 4 shows the completed hand-wrist-forearm surface CAD model with an initial solid design of the orthosis.

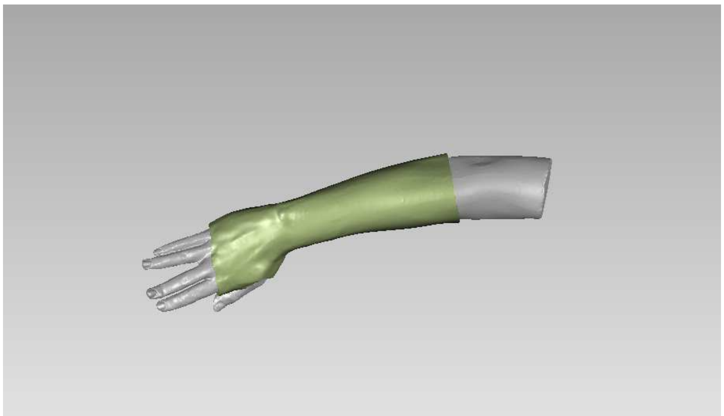


Figure 4: Hand-wrist-forearm CAD model and orthosis.

After splitting the initial model into the upper and lower part of the orthosis, topological optimisation was performed to obtain an improved lighter orthosis design (Figure 3). The first step consisted of defining the material properties and the simulation boundaries, namely, the constraints and solicitations. Polyamide was defined for the material, the two lateral faces along the long side of the orthosis was defined as constrained and the two top and bottom faces were defined with tensile solicitations. In this case, several levels of tensile forces where applied and several results were provided by the software. Figure 4 illustrates the selected optimised design by the patient for the production of the Hand-Wrist-Forearm Orthosis. A thickness of 3 mm was applied to the optimised design for production.

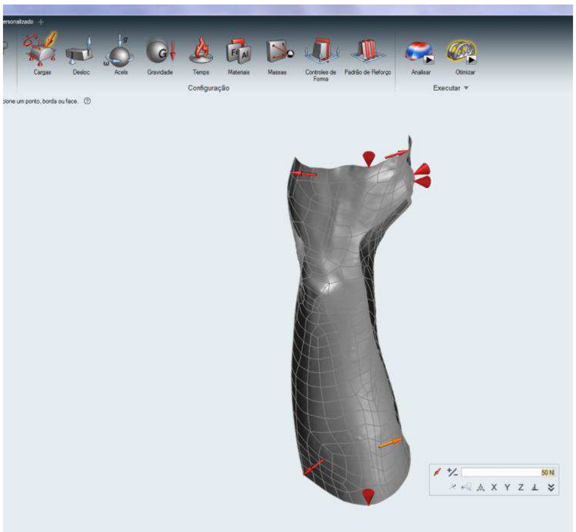
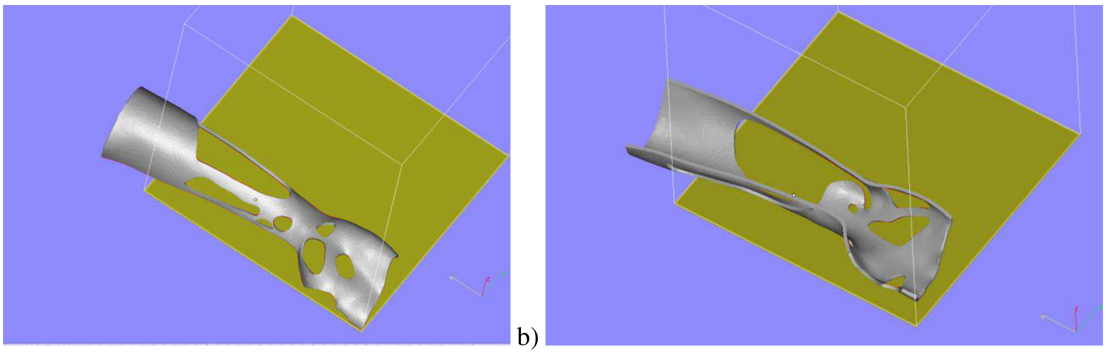


Figure 5: Definition of the constraints and solicitations.



a) b)

Figure 6: a) Lower and b) upper part of the orthosis model.

The next step consisted of producing the orthosis with the aid of an additive manufacturing system. In this case, a HP Jet Fusion 3D 4200 Printing Solution was used and the orthosis was produced in HP 3D High Reusability PA 12 material. After importing the CAD models into the system's building manager software, namely the SmartStream 3D Build Manager, the models were placed in three different positions, namely laying down, lateral and upright. The HP Jet Fusion 3D 4200 Printer has a Layer Thickness of 0.07 to 0.1 mm, which in this case, due to the curved features of the orthosis, the smallest layer thickness was selected in order to avoid the staircase effect on the physical model. The next step consisted of evaluating which position would be the most adequate for the production of the orthosis. Figure 5 illustrates the two halves of the orthosis in the three designated positions. In the laying down position, both parts occupy 1.78 % of the building chamber, have a maximum building height of 63.05 mm and a building time of 3h59min10sec. In the lateral position, both parts occupy 1.3 % of the building chamber, have a maximum building height of 86.54 mm and a building time of 4h54min09sec. In the upright position, both parts occupy 0.36 % of the building chamber, have a maximum building height of 310.02 mm and a building time of 13h37m30sec. As the staircase effect was not significant in any of the tree considered orientations, the decision only was based on the best occupation of the building chamber and the lowest building time, being the laying down position.

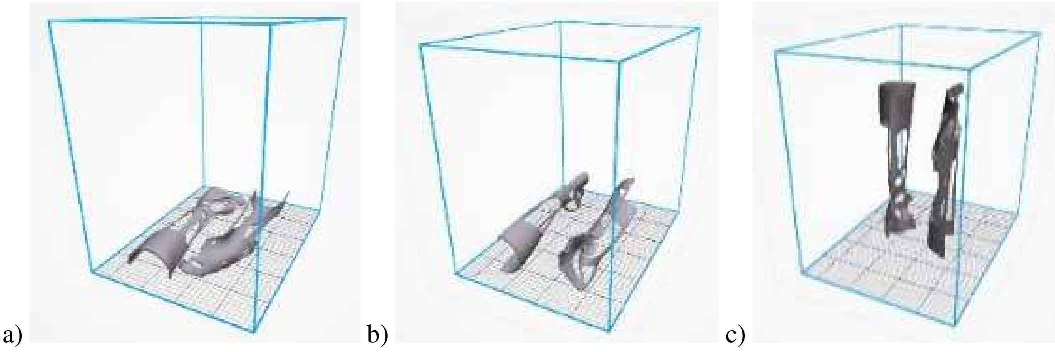


Figure 7: a) Laying down, b) lateral and c) upright position of the orthosis parts for production.

The HP Jet Fusion 3D 4200 Printer is a novel binder jetting process. The printer heads first jet a fusing agent upon the material powder and then a second detailing agent. Then after applying energy to the produced layer, the processed voxels are then fused as illustrated in the Figure 8 [2].

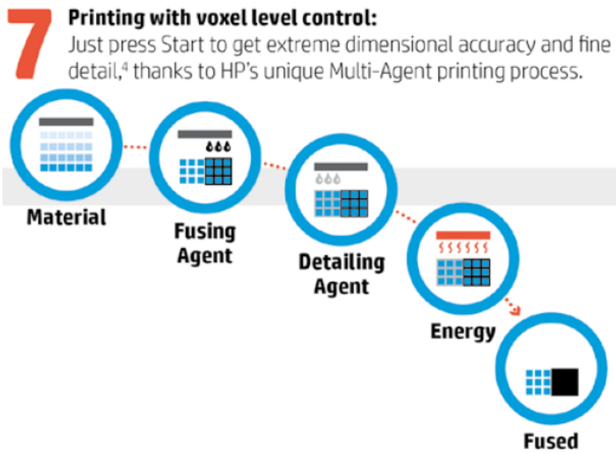


Figure 8: Printing process of the HP Jet Fusion 3D 4200 Printer [1].

Based on this process, the non-processed powder serves as support structure during the entire building process. Once the building process has been concluded, the next step consists of removing the parts from the building chamber and removing the excess powder around the parts. The building chamber is removed from the 4200 Printer and inserted into the Processing Station with Fast Cooling (Figure 9).

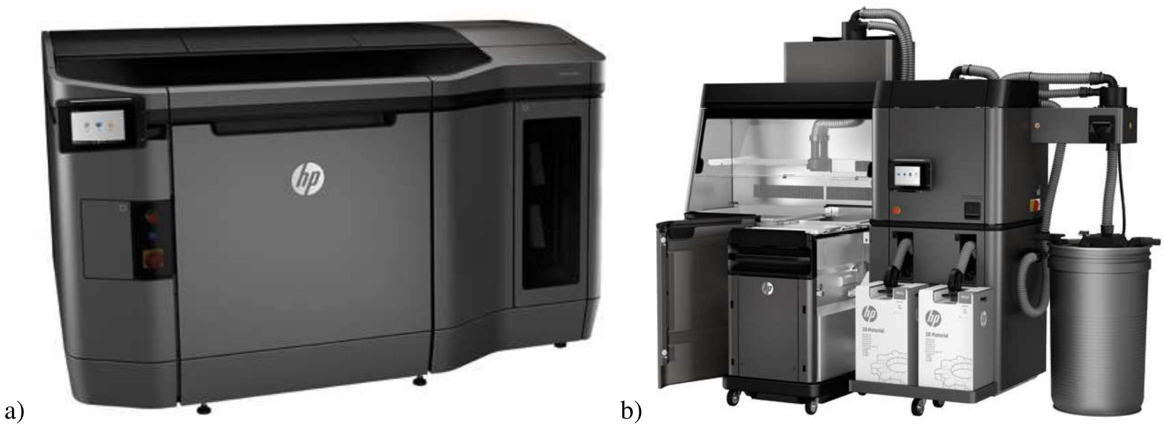


Figure 9: a) HP Jet Fusion 3D 4200 printer and b) HP Jet Fusion 3D Processing Station with Fast Cooling (HP, 2017).

Figure 10 illustrates the several steps involved in the Processing Station with Fast Cooling. The next step consists of air jetting to remove the excess powder and obtain the final parts, as illustrated in Figure 11.

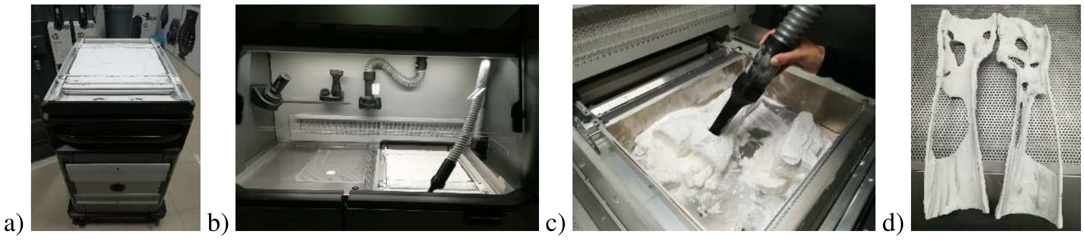


Figure 10: a) building chamber removal from printer b) building chamber insertion into the processing station c) vacuum to remove of the excess powder and d) parts with excess powder.

Figure 11: a) air jetting chamber for excess powder removal and b) final parts of the orthosis.

The final step of the process consisted in validating the produced orthosis on the patient. Figure 12 illustrates the patient testing the orthosis.

Figure 12: Patient testing the orthosis.

3 CONCLUSIONS

Hand-Wrist-Forearm Orthosis come in a varied assortment of configurations and sizes to accomplish many different functions for support and immobilization. Athletic trainers, occupational therapists, physical therapists, orthopaedic doctors and emergency room and ambulance professional personnel often require specific hand splints to help their patients recover or rehab from injuries, or to assist in deformities or spasticity caused by certain health conditions.

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[2] HP (2017) HP Jet Fusion 3D Printing Solution Brochure (November 2017) http://www8.hp.com/us/en/printers/3d-printers.html?jumpid=va_ytv6mxqpr3#JetFusion3Dsolutions