

COPYRIGHT WARNING

This paper is protected by copyright. You are advised to print or download **ONE COPY** of this paper for your own private reference, study and research purposes. You are prohibited having acts infringing upon copyright as stipulated in Laws and Regulations of Intellectual Property, including, but not limited to, appropriating, impersonating, publishing, distributing, modifying, altering, mutilating, distorting, reproducing, duplicating, displaying, communicating, disseminating, making derivative work, commercializing and converting to other forms the paper and/or any part of the paper. The acts could be done in actual life and/or via communication networks and by digital means without permission of copyright holders.

The users shall acknowledge and strictly respect to the copyright. The recitation must be reasonable and properly. If the users do not agree to all of these terms, do not use this paper. The users shall be responsible for legal issues if they make any copyright infringements. Failure to comply with this warning may expose you to:

- Disciplinary action by the Vietnamese-German University.
- Legal action for copyright infringement.
- Heavy legal penalties and consequences shall be applied by the competent authorities.

The Vietnamese-German University and the authors reserve all their intellectual property rights.





RUHR-UNIVERSITÄT BOCHUM



STUDY, DESIGN, AND FABRICATION OF A 3D PRINTED ARM CAST

Bachelor Thesis 
Vietnamese-German University
BINH DUONG 2023

Submitted by: Ngo Huy Luan

RUB Student ID: 19219630

VGU Student ID: 15401

Supervisor: Dr. Tran Tuan Minh

Co-supervisor: Assoc. Prof. Nguyen Quoc Hung

STUDY, DESIGN, AND FABRICATION OF A 3D PRINTED ARM CAST

A Thesis Presented

By

Ngo Huy Luan



Submitted to the department of Mechanical Engineering of the

RUHR-UNIVERSITÄT BOCHUM and VIETNAMESE-GERMAN UNIVERSITY

in partial fulfillment

Of the requirement for the degree of

BACHELOR IN MECHANICAL ENGINEERING

March 2023

Major: Mechanical Engineering

Affirmation in lieu of oath

Ngo Huy Luan

Matriculation Number: 19219630

Title of Thesis: STUDY, DESIGN, AND FABRICATION OF A 3D PRINTED ARM
CAST

I hereby declare in lieu of oath that I have produced the aforementioned thesis independently and without using any other means except the aids listed. Any thoughts directly or indirectly taken from somebody else's sources are made discernible as such.

To date, the thesis has not been submitted to any other board of examiners in the same or a similar format and has not been published yet.



Binh Duong, March 8 - 2023 Vietnamese-German University

Ngo Huy Luan

Acknowledgement

This thesis is written by VGU's support under the grant project number: DTCS2022-001

Firstly, a note of my deepest appreciation to my family for motivating me throughout the project. This project is a magnificent addition to my career objectives, and it have given me great insights into the industry.

I am truly thankful to Professor Tran Tuan Minh and Professor Nguyen Quoc Hung in the Department of Mechanical Engineering, who has the attitude and substance of a true guide. I feel grateful for his esteemed guidance and being a valued encouragement throughout the time working on my thesis.

Now I would take this opportunity to extend my gratitude to Ms. Nguyen Thi Tuu, who has supported and helped me throughout my years studying at VGU. The kind support from her has helped me overcome a lot of obstacle, I would not be as good as I am today without it.

Last but not least, I want to extend my thanks to all the lecturers and professors at this university for providing me with the knowledge I need in engineering field. I am also very glad to have made my friends here, they were always my source of encouragement and have accompanied me throughout the time I study here at VGU.

Abstract

This project focuses on the process of making and testing a 3D printed arm cast. The project starts with obtaining a 3D model of an arm, a Sense scanner was used as it was the only reliable option available. Then the 3D scanned arm was imported into the nTopology (nTop) software to set up an automated process based on the current arm for all subsequent 3D arm models. When the 3D arm cast model has been completed, it is printed at a 3D printing company as a sample model. The sample model is too hard to test realistically so instead, the real-life test is carried out on small test tube and the data obtained will be compared to the simulation data on nTop.

This project has provided an opportunity to gain personal insight into the 3D printing industry and the process of creating a product.



Table of contents

Affirmation in lieu of oath	2
Acknowledgement	3
Abstract	4
Table of contents	5
Table of figures	7
1 Introduction	9
1.1 Research motivation	9
1.2 Brief review of previous research	11
1.2.1 CORTEX orthopedic arm cast by Jake Evill.....	11
1.2.2 Osteoid medical cast.....	12
1.2.3 ActivArmor company	13
1.3 Organization of the thesis	14
2 3D scanning	15
2.1 Introduction.....	15
2.2 Current 3D scanning technology	15
2.2.1 Laser triangulation scanning.....	15
2.2.2 Structured Light 3D Scanning.....	16
2.2.3 LIDAR scanning.....	17
2.2.4 Photogrammetry	17
2.2.5 Contact scanning	18
2.3 Obtaining 3D models of an arm.....	19
3 Design and fabrication of a 3D cast model	21
3.1 Software Introduction	21
3.2 Program automated process for creating cast models.....	21
3.3 Different lattice patterns	28
3.4 Material selection:.....	31

3.5	Analysis of the 3D cast models.....	33
3.6	Result overview	34
4	Printing the 3D model	36
4.1	The 3D printing company and the printer.....	36
4.2	Real-life testing.....	38
4.3	Result discussion.....	40
5	Review, recommendation, and conclusion	44
5.1	Review and recommendation.....	44
5.2	Conclusion	46
6	References	47



Table of figures

Figure 1.1 Charles W. Hull and his 3D printer [Source: IndustryWeek]	9
Figure 1.2 The CORTEX 3D printed orthopedic arm cast [Liz-13].....	11
Figure 1.3 The Osteoid 3D arm cast [TMF-20].....	12
Figure 1.4 ActivArmor’s 3D printed casts [Source: Active armor]	13
Figure 2.1 Principle of laser triangulation scanning [Source: Wikimedia Commons]...	15
Figure 2.2 Scanning with structured light. [Source: Bitfab].....	16
Figure 2.3 Photogrammetry method example [Dino-13].....	18
Figure 2.4 Contact-based scanning [Source: 3D-Prototype]	19
Figure 2.5 One of the final models	20
Figure 3.1 nTopology’s logo [Source: nTopology]	21
Figure 3.2 Imported 3D scanned model.....	22
Figure 3.3 Implicit model	22
Figure 3.4 3 planes as trimming tools.....	23
Figure 3.5 Trimmed model	24
Figure 3.6 Hollowed out model	25
Figure 3.7 Rims and boundary planes	26
Figure 3.8 Forming a lattice.....	27
Figure 3.9 : Finished cast.....	27
Figure 3.10 : Cast placed sideways	28
Figure 3.11 Lattice moved to the left.....	29
Figure 3.12 A tube placed along the cast.....	29
Figure 3.13 Lattice pattern gravitate towards tube	30
Figure 3.14 Different type of lattice	31
Figure 3.15 Poor lattice due to incorrect mapping.....	32
Figure 3.16 Placement of forces and restrained parts	34
Figure 3.17 Deformation of the cast in simulation	35
Figure 4.1 3D Smart Solution’s logo [Source: 3D Smart Solution]	36
Figure 4.2 Form3L model 3D printer	37
Figure 4.3 SLA printed test tube.....	37
Figure 4.4 3D Printed arm cast	38
Figure 4.5 Before testing	39
Figure 4.6 After testing	39

Figure 4.7 Some time after the test	40
Figure 4.8 Results from 3-points testing.....	41
Figure 4.9 Zoomed-in chart	41
Figure 4.10 Simulation of test tube.....	42
Figure 5.1 Block coding of nTopology.....	45



1 Introduction

1.1 Research motivation

Charles W. Hull, who pioneered 3D printing, was an American furniture builder that had the idea of using computer-aided design software (CAD) to make a system that can create three-dimensional objects. The system Hull developed engrave layers of acrylic into shapes using ultraviolet laser before stacking them to build an object. In 1986 he patented his invention, and in 1988 he found the 3D System Corporation. Three decades since he then, 3D printing has found its way into many industries and its application across is now being explored, including its potential in healthcare services.

As 3D printing developing, its medical application will continue to broaden, becoming more advanced and economically accessible for everyone. Currently, medicine's most impressive recent advancements can be credited to 3D printing, it includes 3D printed prosthetic devices, bones, vascular tissue, as well as some medical devices. Although it is nowhere near being widely applicable, it has proven its potential in making changes to the medical field.

Vietnamese-German University



Figure 1.1 Charles W. Hull and his 3D printer [Source: IndustryWeek]

As 3D printing technology becomes more affordable, it would be a more advantageous approach to treat bone fractures using 3D printed orthopedic casts. Although plaster cast are still an effective treatment for broken bones, their limitations also persist up to now. Besides the fact that these casts are uncomfortable to wear, other downsides exist:

- The weight and bulkiness of the plaster casts can restrict the patient's movement.
- The casted area during treatment is inaccessible and cannot be easily cleaned, potentially leading to infection or rash.
- Plaster casts are not waterproof and will get broken down if it got wet, thus interrupting the healing process.

3D printed cast can provide additional benefits based on the designs, on top of being able to address the limitations of plaster cast. While 3D printed casts are not yet widely available, they are becoming more well known as more people learn about the 3D printing technology and the benefits it can offer.



The 3D printing industry in Vietnam have been rapidly growing, which open up an opportunity to introduce this technology into the country's health care system. Fractures, or broken bones, are among the most common orthopedic problems, about 178 million new cases of fracture occurs globally in 2019 alone [OSU-16]. The most common fracture for ages prior to 75 is wrist fracture [LANCET-2021], so the target of this project is to create an arm cast suitable for wrist fractures.

However, their effectiveness and durability are still being evaluated and compared to traditional casts. Additionally, not all hospitals and clinics have access to 3D printing technology. The cost of 3D printed casts is also higher than that of traditional casts. It is important to note that 3D printed cast can not be an absolute replacement for other treatments such as physical therapy, pain management, and rehabilitation, which are all critical for a full recovery.

In conclusion, 3D printed casts are a promising alternative, but more research is needed to determine if they are the right choice for medical treatment. Ultimately, the decision should be made by a medical professional, considering the specific needs and circumstances of each patient. Factors such as type and locations of the fracture, the patient's age, medical history, and overall health, should be considered when deciding on the most appropriate treatment.

1.2 Brief review of previous research

Although proven to have more advantages than regular plaster cast, 3D printed ones are rarely used as replacement. This is because 3D printed cast are still a new product on the market, with few to none commercially available product [Chen-2017].

1.2.1 CORTEX orthopedic arm cast by Jake Evill

Developed in 2013 by Jake Evill [Liz-13], his CORTEX cast is among the first 3D printed orthopedic cast (Figure 1.2). Evill used his knowledge of human bones anatomy and x-ray data to make his cast according to the arm parameters and the location of injury as well. His idea is to make a program that automatically process the x-ray data with the patient's measurements make a cast that have denser support focused on the fracture itself.

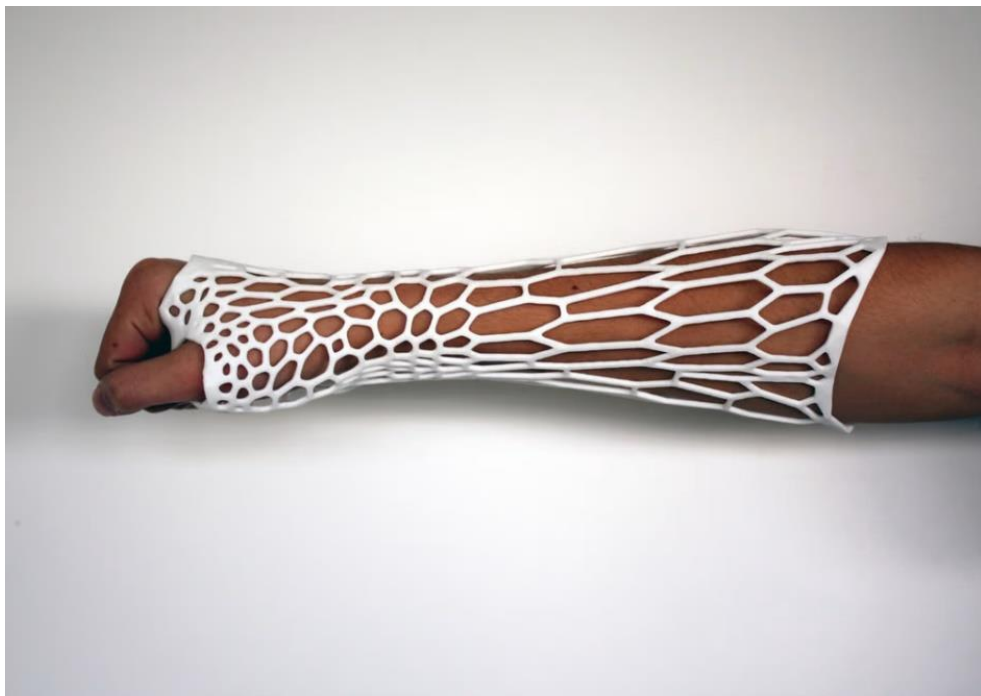


Figure 1.2 The CORTEX 3D printed orthopedic arm cast [Liz-13]

1.2.2 Osteoid medical cast

In 2014, Deniz Karasahin designed the Osteoid medical cast (Figure 1.3) to participate the A'Design Award & Competition; this cast design won them the gold medal [TMF-20]. However, the cast is currently not commercially available since the development of the project was halted so that the designer can seek out partners to join their project.



Figure 1.3 The Osteoid 3D arm cast [TMF-20]

Apart from fixing the arm in place, this cast also have an integrated system to ensure and promote faster bone recovery. The bone recovery process is quickened with LIPUS technology by using low-intensity ultrasound pulses. These pulses act as a signal through the arm, to which the cells react with a mechanical biochemical response that boost the recovery process.

However, this cast is also not commercially available as the proposed ultrasound healing therapy was questionable and inconclusive. As said by Doctor Jonathan Cluett “there is really no current evidence to support the use of ultrasound for healing. Most of the benefits of ultrasound have been found in non-clinical settings”. Nevertheless, the 3D printed cast has proven that technologies like LIPUS can be integrated into it to help with the recovery process.

1.2.3 ActivArmor company

Currently, ActivArmor is the only company in the United States whose design and products are commercially available and is covered by most insurance company. At ActivArmor, there are many prebuilt designs, they come in various shapes and sizes for all kind of injury (Figure 1.4). The time required for the production and delivery of a custom cast is about 4 working days and a free temporary splint is given to the patient while waiting for their cast.



Figure 1.4 ActivArmor’s 3D printed casts [Source: Active armor]

Although being new to the market, the 3D printed orthopedic hand cast is very popular among people when considering its advantages over regular plaster casts. After reviewing the previous cast designs, it is concluded that the most optimal way to make a 3D printed cast is to create it as two separated pieces with connectors. The lattice of the cast should also be easily modified in regard to the injury to achieve the best result.

1.3 Organization of the thesis

The first chapter is an introduction to 3D printing technology, its basic principle, history, and its application in the medical field are outlined in order to better define some specific aspects and benefit of this technology. Chapters 2 – 3 explain various scanning methods and steps which make up the whole process of creating a 3D model of an arm cast. Chapter 4 discusses the testing result on arm cast model via simulations and a live test run. Chapter 5 contains final conclusion of how this project have given new personal insights into the process of creating 3D printed arm casts, and recommendation of what program to use in the process.



Vietnamese-German University

2 3D scanning

2.1 Introduction

3D scanning is a method to capture the physical measurement and shape of an object, the object is then digitally reconstructed as a 3-dimensional representation. Collected 3D digital copy data can be used for many applications such as motion capture, gesture recognition, orthotics and prosthesis, robotic mapping, rapid prototyping, and reverse engineering.

2.2 Current 3D scanning technology

2.2.1 Laser triangulation scanning

The triangulation 3D laser scanners probe the environment with laser light from the laser emitter, it shines a laser on the subject and the location of the laser dots are recorded by a sensor. Through the camera's field of view, the laser dots appear at different places depending on where the laser strikes. This technique is known as triangulation, it got that name because the laser dot, the sensor, and the laser emitter need to form a triangle to make an effective scan. The position of the camera, the laser emitter and the object would determine the shape and size of the triangle. Nowadays, a laser stripe is used instead of a laser dot, it can swept across the object to speed up the data acquisition process.

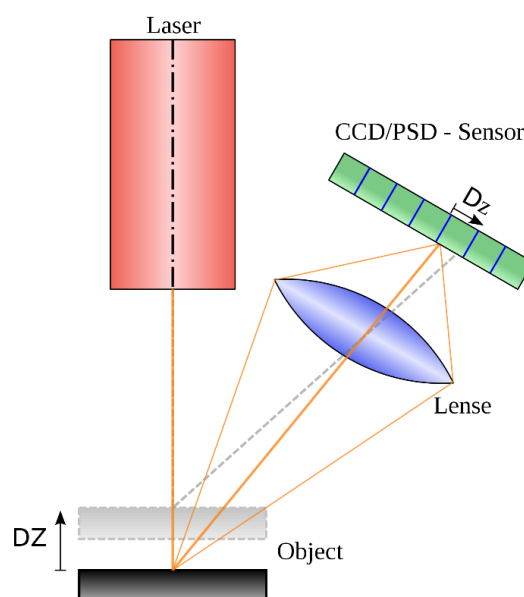


Figure 2.1 Principle of laser triangulation scanning [Source: Wikimedia Commons]

The main benefits of laser triangulation scanning are that it is simple in design, portable, and easy to use. The other benefit is that it is less sensitive to changing light, so that the scanning result will not be altered by ambient light most of the times. The only downside of this scanning method is that they cannot capture transparent or shiny surfaces.

2.2.2 Structured Light 3D Scanning

These 3D scanners project a light that have pattern consisting of bars, blocks, or other shapes onto an object. Then they have one or more sensors to look for the deformation in those patterns and determine the object's 3D shape. The principle of this scanning technique is the same as triangulation scanning.

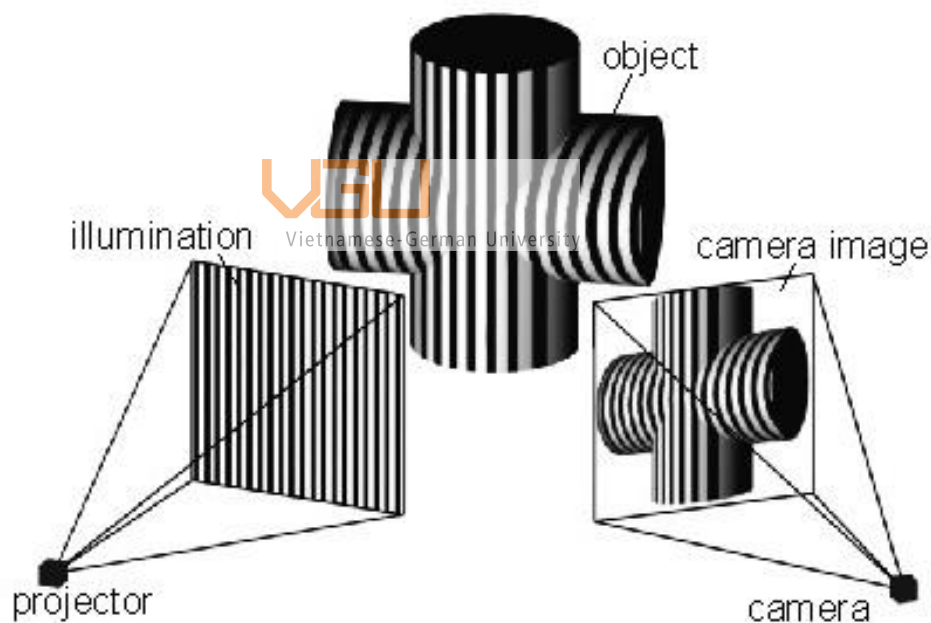


Figure 2.2 Scanning with structured light. [Source: Bitfab]

Compared to normal triangulation scanning, structured light scanning can cover a larger scanning area with faster scanning time while keeping the benefits of being simple in design portable, and easy to use. The structured light scanning method is also eye-safe for scanning humans and animals because they have the option to use LCD light instead of laser light. Structured light 3D scanners have various price points depending on resolution and accuracy.

2.2.3 LIDAR scanning

LIDAR scanners employ penetrating laser pulses, such as ultraviolet or near infrared light, to capture the organization and structure of the objects. The pulses from these scanners can target or go through a wide range of materials, which including non-metallic and moving objects such as rocks, rain, chemical compound. The laser rangefinder at the core of the scanner will find and determine the shape and size of the object, they also calculate the distance to the object by timing the round trip of each pulse of light.

Phase-shift scanner is another type of LIDAR scanner, the similarity they shared is that they both use pulse-based system; but similar to how the vernier scale on a caliper work, phase-shift systems can also adjust the power of their laser pulse to further refine distance between the object and scanner. Although phase-shift measurement method is quieter and give more accurate result, they cannot be used for long-range scanning like pulse-based scanners.



Vietnamese-German University

LIDAR scanner are long range scanners, pulse scanners can scan objects that is over 1km with an optimal operating range of 5-300 meters while phase shift scanners have higher accuracy but most systems only have a maximum range of 80 meters with some can reach up to 120 meters. These scanning devices are also portable and contribute greatly to archeology and geology.

2.2.4 Photogrammetry

This type of scanning technique involves stitching together photographs of an object taken from different angles. The photos are then processed by a specialized software, the software assign pixels to the photos according to the lighting and shape of the object and then it try to connect those pixel together to create an 3D object.

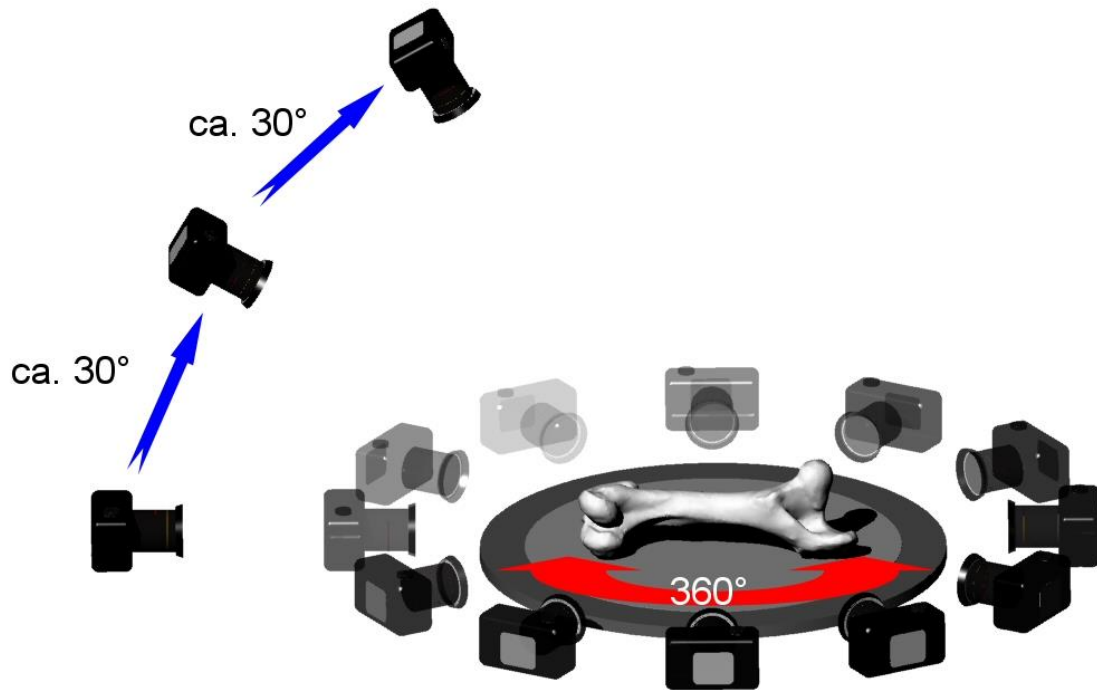


Figure 2.3 Photogrammetry method example [Dino-13]

Photogrammetry biggest advantages is its safety, ease of use, and highly accessible. The captured images can be process with many software such as 3DF Zephyr, Reality capture, Airsoft Metashape, Blender, many of which are free to use. The only downside with this method of 3D scanning is the amount of time it takes to prepare the photos and the accuracy of end result depends on the resolution of the images.

2.2.5 Contact scanning

This is the only scanning method known that involves physical contact of the probe onto the surface of the object. The touching probe move all over the object, collecting the data needed to create a high precision digital reconstruction while the object is firmly held in its place so that it does not move in the scanning process.



Figure 2.4 Contact-based scanning [Source: 3D-Prototype]



Vietnamese-German University

This method of scanning involves only physical contact with the surface of the object, so even transparent and reflective surface can be scanned accurately with contact scanning, which is a major advantage over most 3D scanners. The disadvantages with contact 3D scanning are its high price tag and its slow scanning speed.

2.3 Obtaining 3D models of an arm

The 3D scanner used in this project was a Sense 3D scanner which use the Kinect system. The system was first used as one of Microsoft's Xbox gaming devices, it recreates physical image in digital form by scanning and detecting motions through a system of three vital pieces: a depth sensor, a multi-array microphone, and an RGB color VGA video camera.



Figure 2.5 One of the final models

The scanning process for the Sense scanner is fairly simple: I started the software and choose the size of the scanning box, which can range from 0.1 to 12 meters. The scanner started scanning after I hit the spacebar button, a series of on-screen prompts appeared on the screen to track the distance of the scanner and the object as I move. Moving too far or too close and the program will warn me with colored prompts, I am also notified with an on-screen note if the scanner have lost track of the object. While the scan is in progress, a rough model of the scanned part appears and rotates accordingly to the scanner, this helped track is created by the software to show your scanning progress.

The 3D models are then edited using the scanning software, it removed bits of misplaced pixels and cropped out unnecessary parts to obtain clean models for further selection.

3 Design and fabrication of a 3D cast model

3.1 Software Introduction

The process of making a cast model based on a 3D scanned arm was done using nTopology (nTop), which was found in 2015. The software can aid engineer and designer to create very complex geometry that is able to meet the requirements of high-performance products.



Figure 3.1 nTopology's logo [Source: nTopology]
VGU
Vietnamese-German University

nTopology is a unique and powerful tool for additive design, although it doesn't have as many functions as a modeling platform like Autodesk, its ability to help with design manipulation and optimization is one of, if not, the best. Ideal use case for nTop is to modify, integrate lattices structures, and simulation the imported computer aided design (CAD) or mesh file. The interface of nTop is extremely intuitive and operates through a system of function blocks that act as visual code, users can use these blocks by dragging them with the mouse to design space and adding connect them with other blocks.

3.2 Program automated process for creating cast models

Step 1: Import 3D model

The nTop program modify objects that is in their implicit form so in order to produce a model of the hand cast, the first step is to import the 3D scanned model of an arm and convert it to an implicit body so that it can be modified by the program.

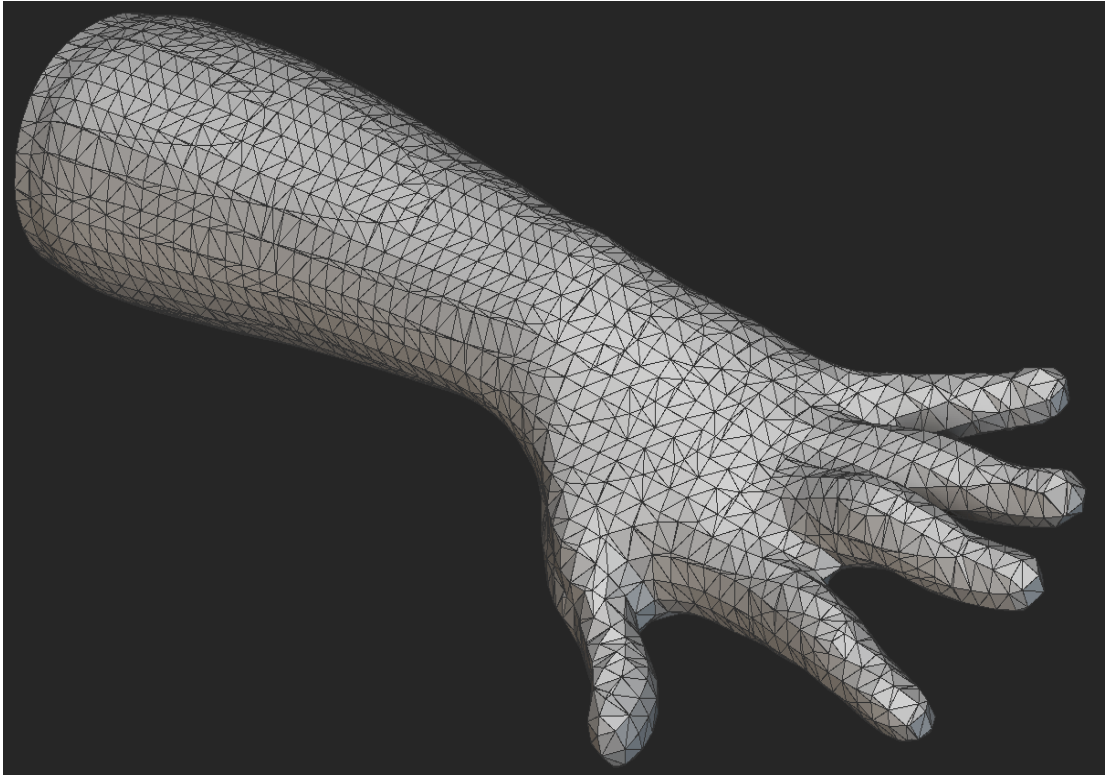


Figure 3.2 Imported 3D scanned model



Step 2: Convert to implicit model



Figure 3.3 Implicit model

Step 3: Create trimming tools

The implicit model is trimmed via trimming tools to create a base model for the cast. The trimming tools are defined by three planes, each is parallel to the knuckles, the base of the thumb, and the end of the forearm. The planes' placement can be changed to customize the base cast.

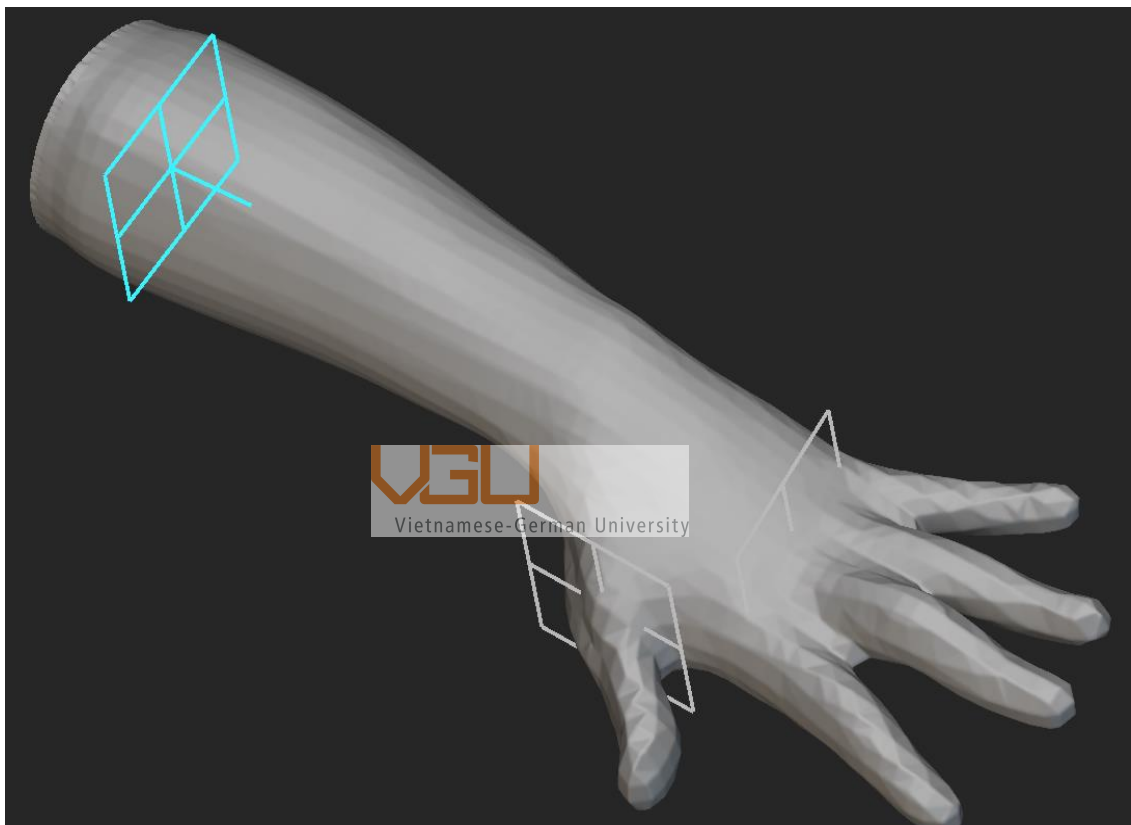


Figure 3.4 3 planes as trimming tools

Step 4: Trim out the fingers

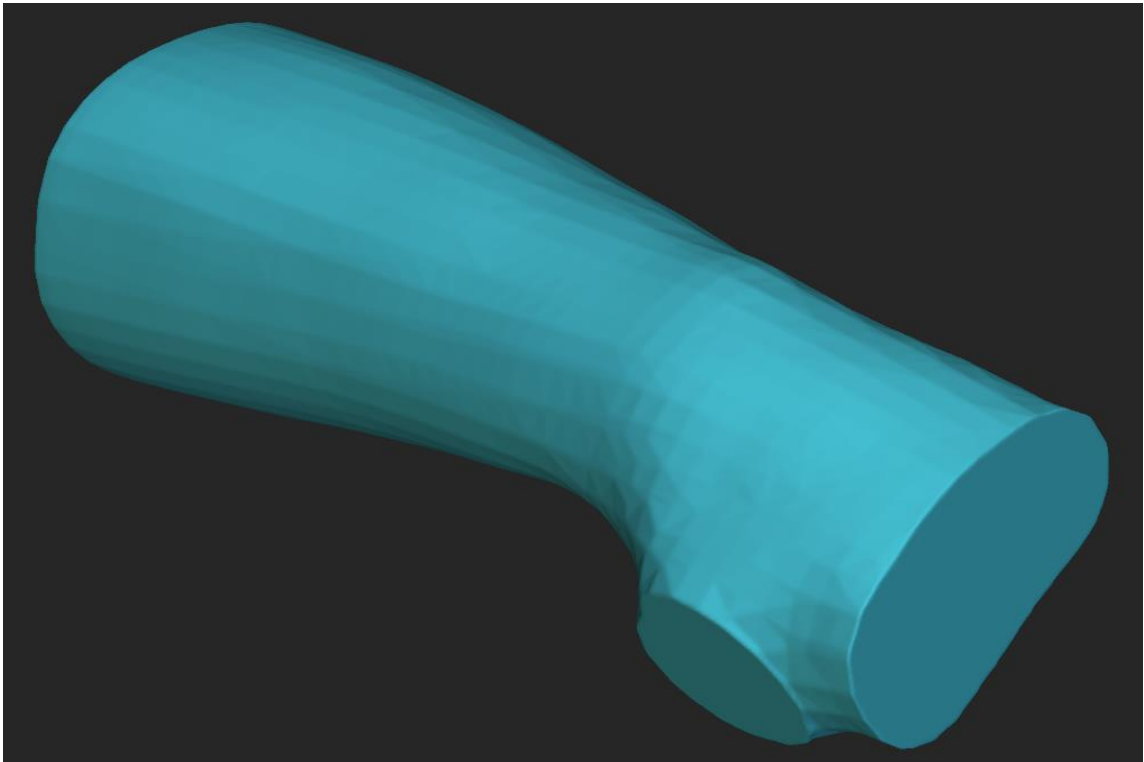


Figure 3.5 Trimmed model
VGU
Vietnamese-German University

Step 5: Hollow out the inside

The base cast is then hollowed using by subtracting the implicit model of the arm from the base cast. At this stage, the 3D model now bears some resemblance to that of normal plaster cast.

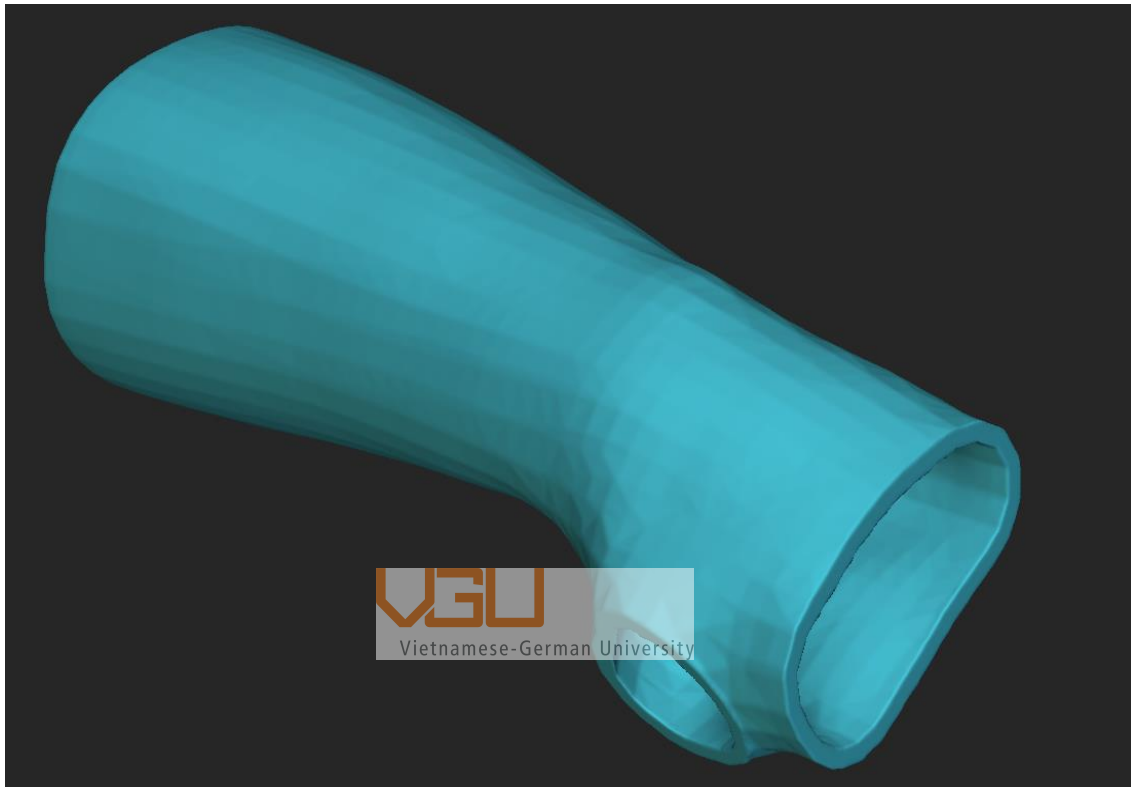


Figure 3.6 Hollowed out model

Step 6: Create the rims

The rims for the cast are created by setting up 3 planes, each parallel to the trimming planes, to cut out parts of the base cast. Parts that will be the rim for the cast are marked blue, the rim thickness and its length can be customized by adjusting the distance between of the paralleling planes. The leftover part will be the design space of the cast are marked brown.

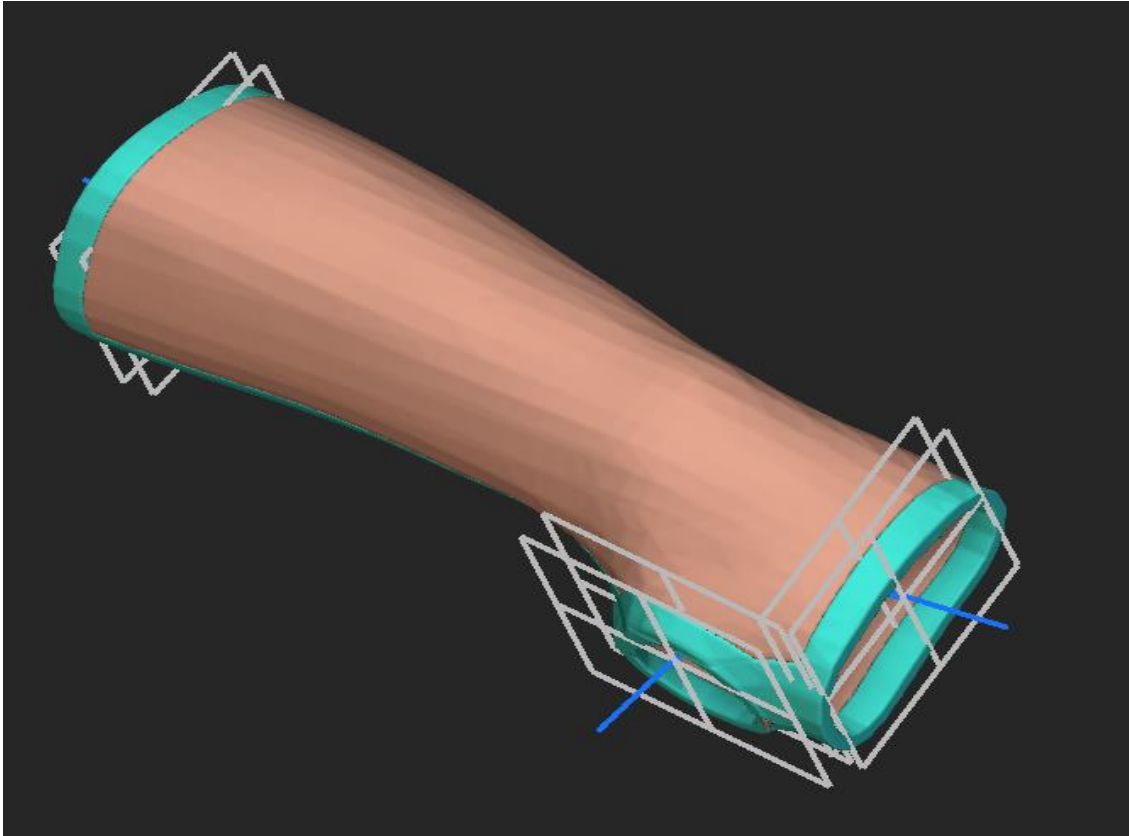


Figure 3.7 Rims and boundary planes



Vietnamese-German University

Step 7: Create the lattice

nTopology software have a built-in lattice generation program, which is then used to create a Voronoi lattice on the surface of the design space. The pattern of the lattice can be modified by using a variety of variables such as: point count, relaxation iterations, random seed, spatial weighting, thickness; and their function are as follows:

- Point count is the number of points distributed onto the design space, the lattice is created using those points.
- Relaxation iterations are number of iterations to evenly distribute the points.
- Random seed is the seed value to generate randomness.
- Spatial weighting is an optional input to control the spacing of the generated points.
- Thickness determines the horizontal thickness of the pattern.

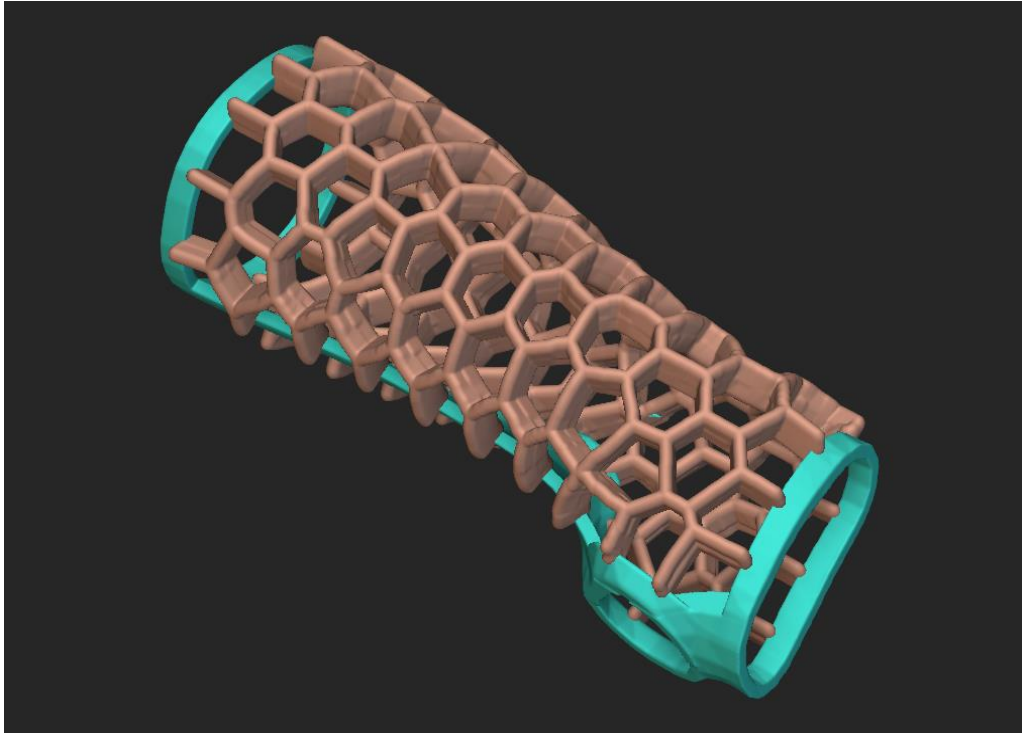


Figure 3.8 Forming a lattice

Step 8: Combine the rims and the lattice


Vietnamese-German University

The final step is to combine both the rims and the pattern together to create a complete 3d model.

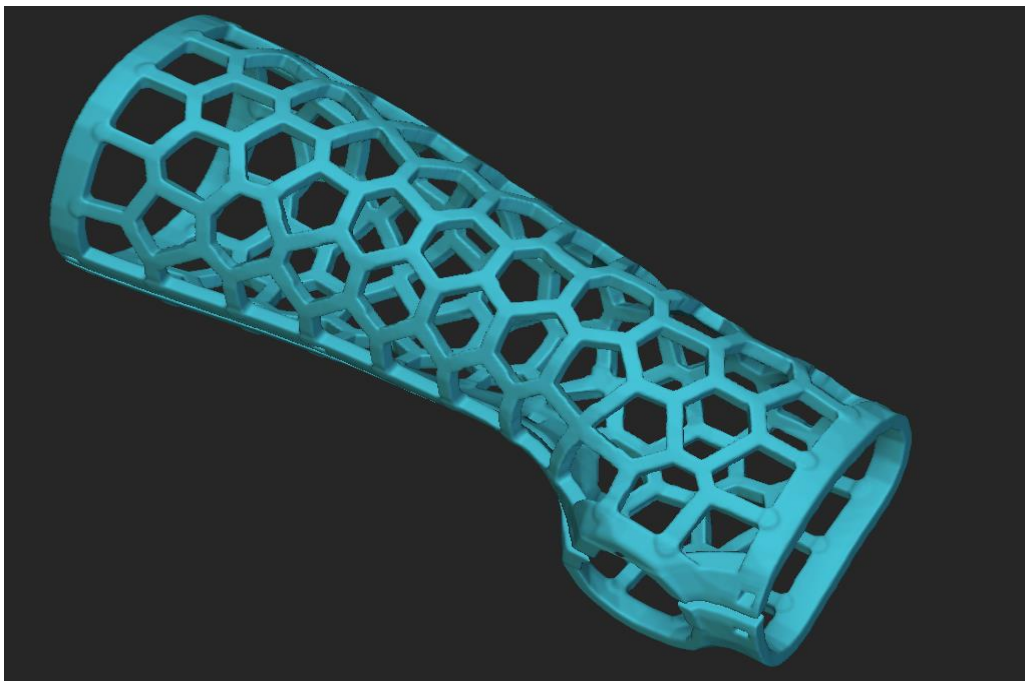


Figure 3.9 : Finished cast

Since the program for the modeling process has been completed, any subsequent arm model imported in will be automatically turned into an arm cast. Depends on the device the processing time can takes as long as 30 minutes to 1 hour.

3.3 Different lattice patterns

For regular models obtained from 3D scanning, the only type of lattice that can be use are Voronoi lattice. Depends on how much use the relaxation iterations, the Voronoi lattice can have randomly generated small and big circles on the surface or a hex-like pattern. These patterns can then be further customized using spatial weighting.

Spatial weighting, as mentioned before, is an optional input to control the spacing of points used to generate the lattice. The method can be used by simply set its input to be planes or objects, the input planes and objects will attract points toward them.

In Figure 3.10, the input is a plane located on the left so the points are attracted there, the lattice generated would have increasingly smaller hexes when getting closer to the plane.

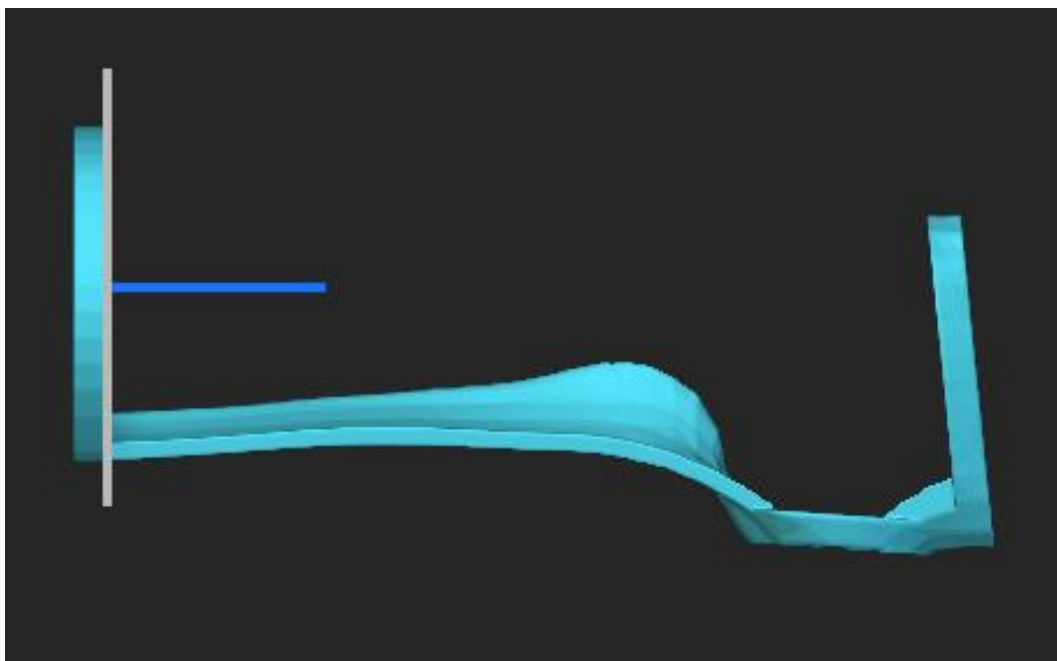


Figure 3.10 : Cast placed sideways

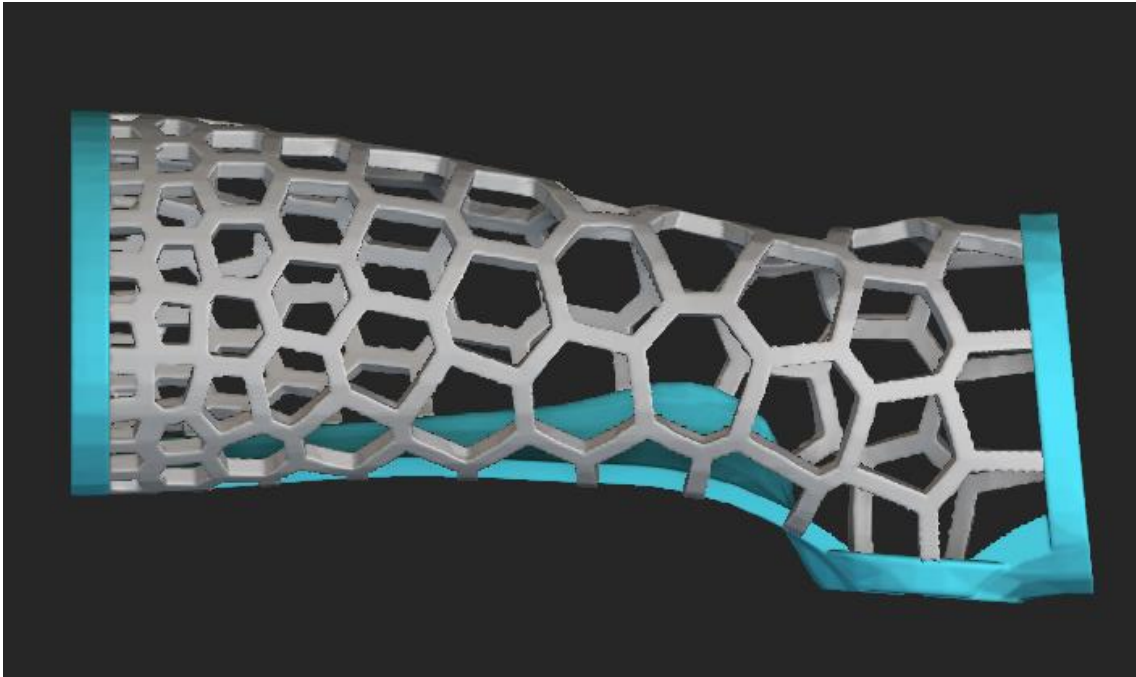


Figure 3.11 Lattice moved to the left

If the input for spatial weighting is an object, for example, a tube that runs along in the middle of the arm cast like in Figure 3.12, then the lattice's hexes would gravitate towards the object instead. The input object can be any shape or even multiple objects with different shapes in order to get the desired lattice pattern.

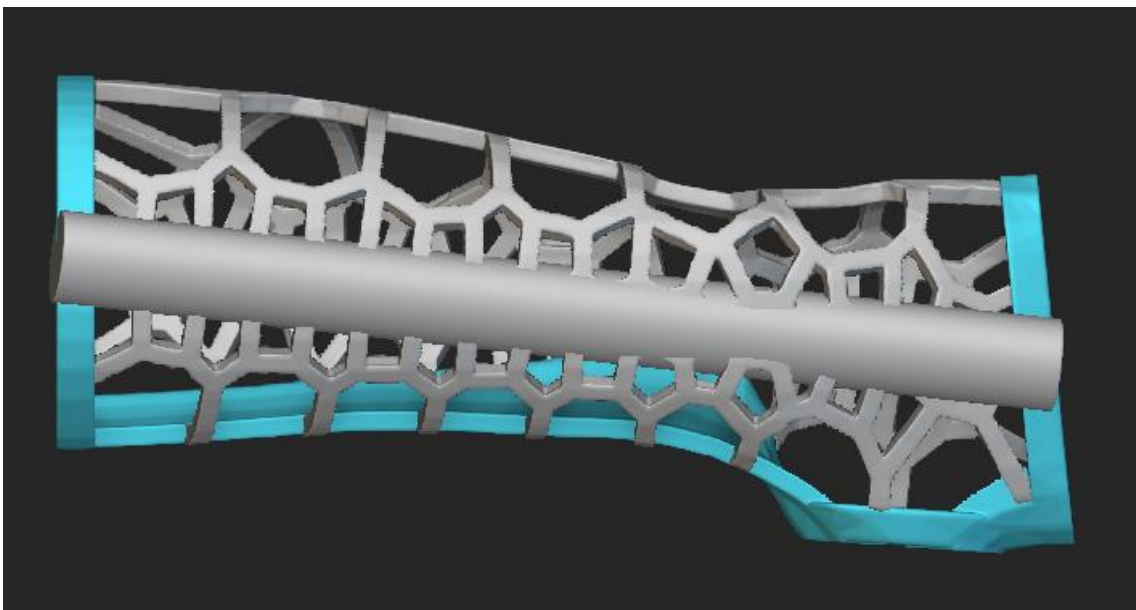


Figure 3.12 A tube placed along the cast

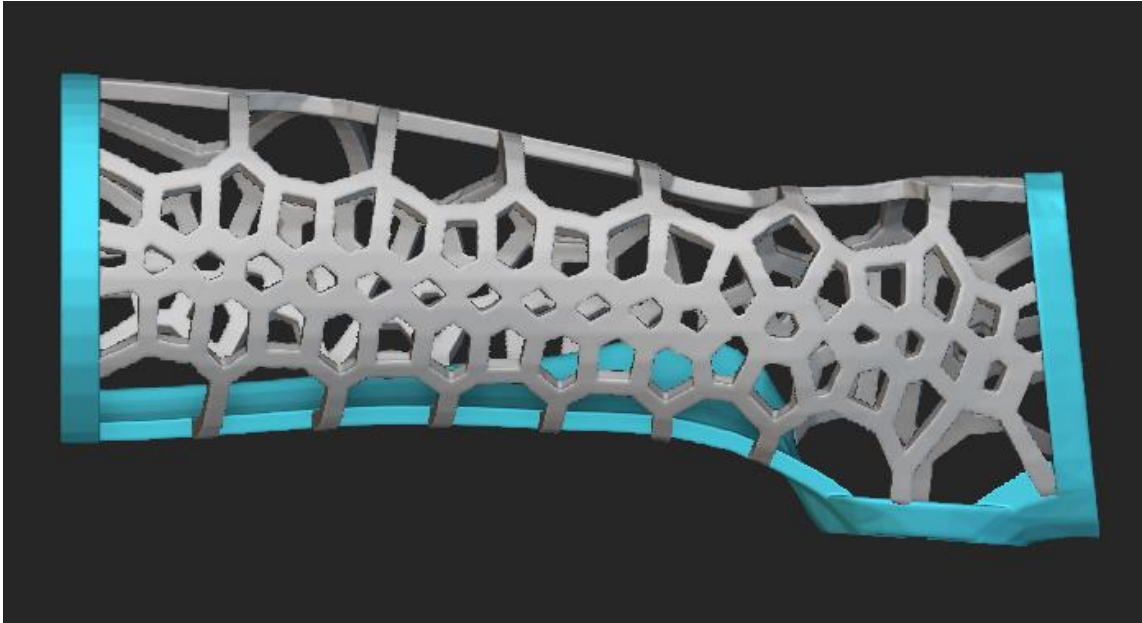


Figure 3.13 Lattice pattern gravitate towards tube

Models that are created by using CAD, or any similar program, can customize their lattice pattern by using cell mapping. This method could create better and more customizable lattice pattern for the arm cast by mapping the area and assign small block of cells on it.

Vietnamese-German University

The cells can be graph with different ready-made patterns in nTopology or they can use their own customized cell. Cell mapping can also be used with spatial weighting to further modify the lattice pattern.

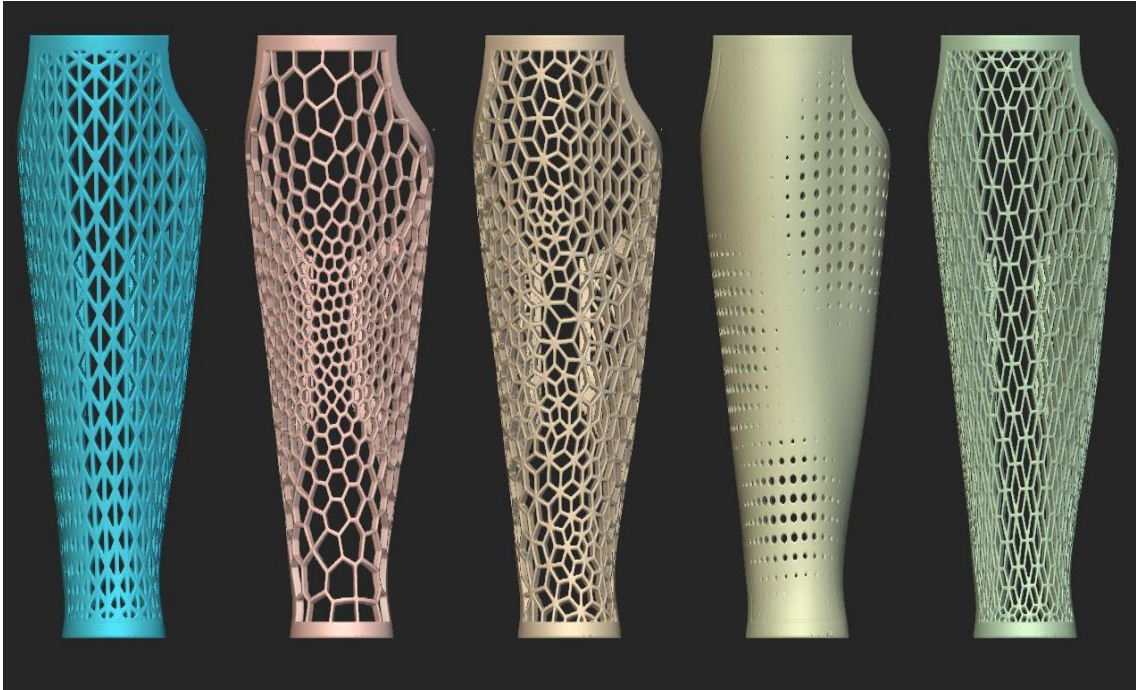


Figure 3.14 Different type of lattice

However, cell mapping does not work directly on 3D scanned models because the mesh of those models is usually inconsistent, which leads to incorrect mapping and errors. As seen in Figure 3.15, due to incorrect mapping the lattice creates multiple overlapping layers of itself. When the lattice pattern gets close to the rim, it condenses and make a surface that is uneven and porous.

3.4 Material selection:

To compete with plaster cast hardness, the desired material properties would have to both tough and durable. There are many categories of resin to choose from Formlab's library, one of the categories is conveniently consist of only tough and durable resins for printing. In this category, there are three different resins with different properties when printed:

- Durable: for soft and pliable parts that bend easily and spring back slowly.
- Tough 1500 (T1500): for stiff but pliable parts that can bend slightly but spring back quickly.
- Tough 2000 (T2000): for stiff and sturdy parts that are difficult to bend.

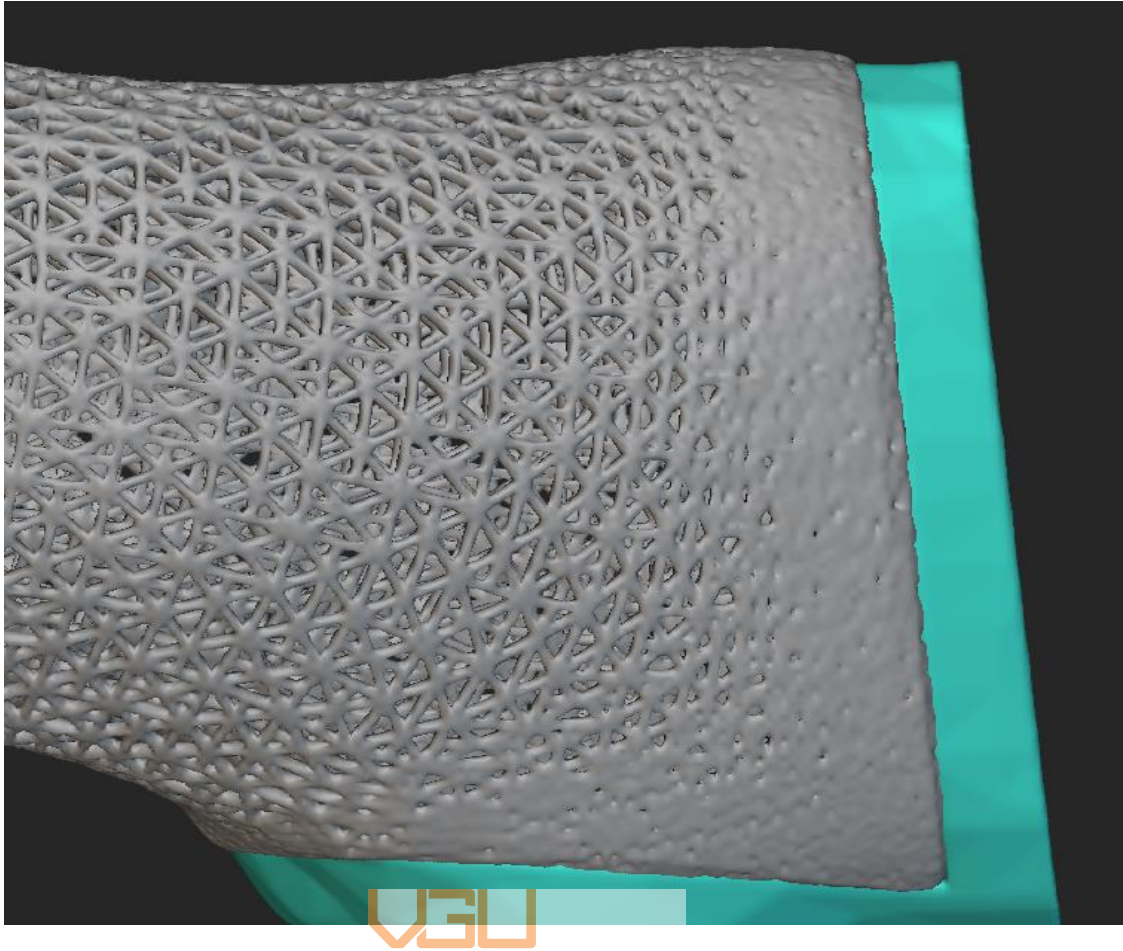


Figure 3.15 Poor lattice due to incorrect mapping

T2000 would be perfect for a cast for its strength alone but the stiffness of this material prevents it from deformation and thus prone to be broken upon receiving sufficient force. This is where T1500 comes in, although it is not as sturdy as T2000, it can bend better than T2000 when received a large force and spring back fairly quickly.

Furthermore, an important note is that T2000 is mostly used for making mechanical parts; while according to Formlab's catalog [Form-2021], T1500 material has been evaluated as a skin contacting device in accordance with ISO 10993-1 and pass the requirements for biocompatibility endpoints such as: not Cytotoxic, not an irritant, and not a sensitizer.

3.5 Analysis of the 3D cast models

Simulations are powerful tools, enabling the user to get the results that is normally only obtainable through field testing. From simple to complex, simulations program in nTopology follow a basic format:

- Convert normal mesh into Finite Element (FE) mesh.
- Give the simulation material properties.
- Combine FE mesh and material properties to create an FE model.
- Add boundary conditions to the FE model. Those conditions include forces, displacement restrains, heat generation, pressure, and more.

After setting up these elements, you can run an analysis. There is a choice of static, buckling, thermal analysis, and nonlinear thermal analysis. Each analysis type utilizes the FE model, its material properties and boundary condition to return the results.

For the current cast, only the static analysis is needed because durability is a cast most prominent feature, and it is the topic most people would talk about when comparing normal plaster cast with 3D printed cast. The force was applied on the wrist of the cast since this cast was meant for patients with wrist fracture.

The T1500 Young's modulus is 1.5 GPa, the material's density is 1.11 g/cm³. The cast is 5mm thick and its bottom side is restrained. The force applied on the wrist area of the cast is 1000N. In Figure 3.16, the part that is highlighted red is where the force was applied, and the green highlighted are parts the where the model was restrained.

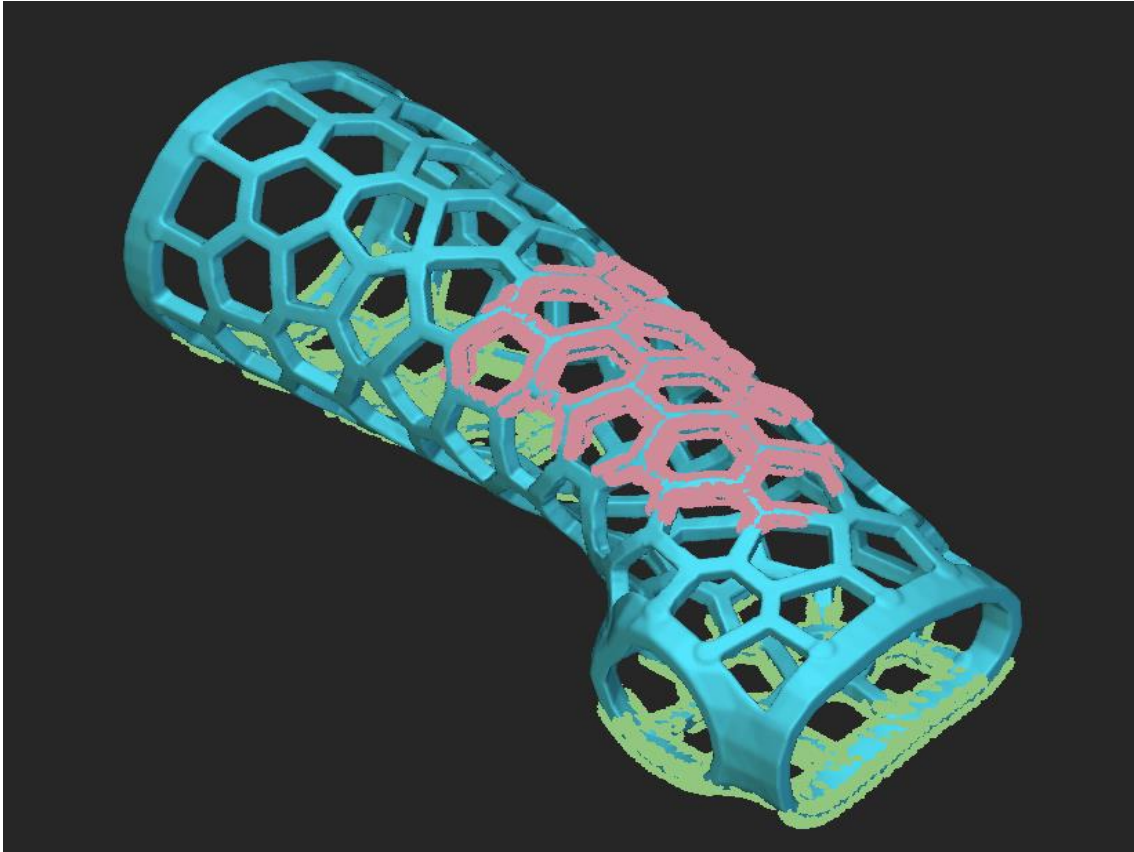


Figure 3.16 Placement of forces and restrained parts



Vietnamese-German University

3.6 Result overview

The result show that the cast maximum deformation would be about 3mm if there was a force of 1000N distributed on to it. This result is only theoretical, it required a real-life test to see how accurate the simulation was.

However, the cast was too uneven to put in the testing machine, so a test tube was created to replace it. The idea is to analyze the test tube in the simulation and then compare it with the result from the real-life experiment, if the two results are not the same, then the tensile modulus of material in the simulation will be modified so that we can have matching results.

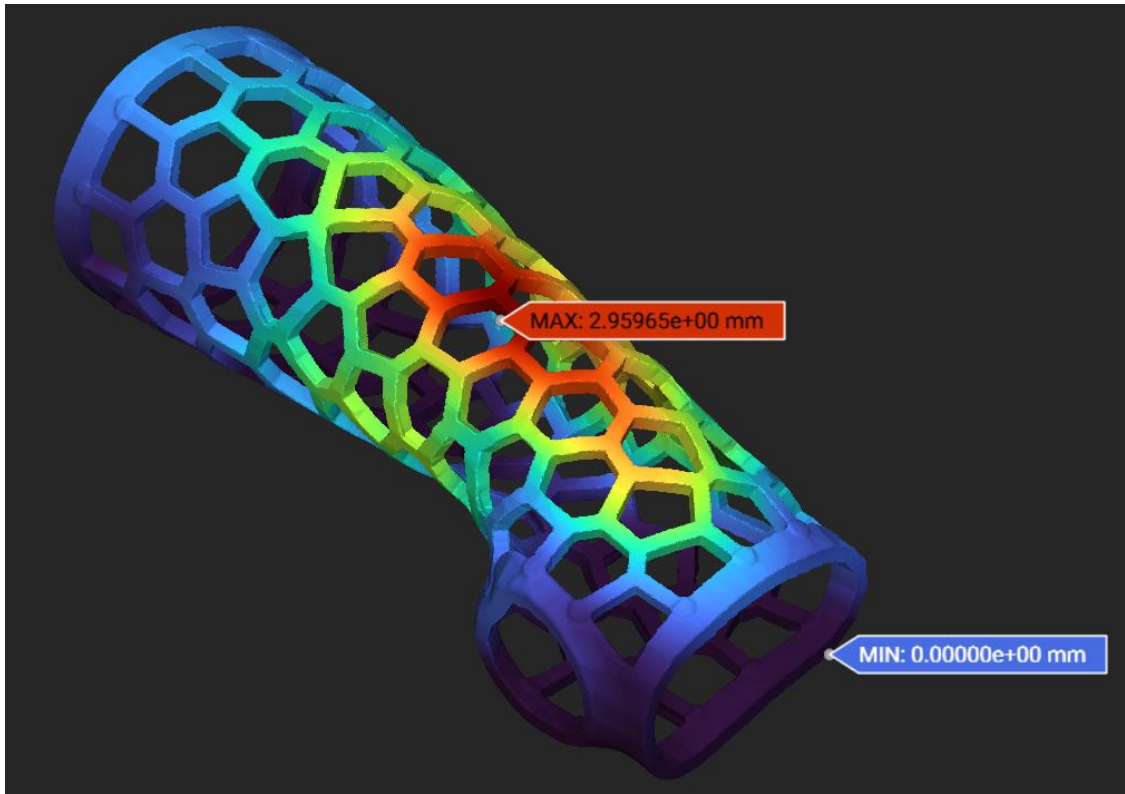


Figure 3.17 Deformation of the cast in simulation

4 Printing the 3D model

4.1 The 3D printing company and the printer

The models were printed at a 3D printing company called 3D Smart Solution (3DS). They have many printers in various size and a wide array of material for customer to choose.



Figure 4.1 3D Smart Solution's logo [Source: 3D Smart Solution]

The 3DS company offers 2 ways to print a 3D model:

- Fused deposition modeling (FDM)

This method of additive manufacturing extrudes materials through a nozzle, melt and then joined them layer by layer to create 3D objects. Generally accepted as the simplest way to 3D printing stuffs, it is also easily accessible, and widely popular.

- Stereolithography (SLA):

SLA works by using a screen that is under a liquid resin reservoir to project laser on to a submerged upside-down platform, this hardens the resin onto the platform to create the desired 3D shape. The platform that is holding the model move up after each layer was finished. This method is more expensive than FDM printing, but it offers more material to choose from, and can print objects with complex geometry.



Figure 4.2 Form3L model 3D printer

SLA was proven to be a better choice since it can print much finer layer than FDM, this way the 3D printed object can achieve better durability. The printer used at 3DS company was a medium sized Form3L model made by Formlabs, it would take about 48 hours to print a 1:1 model of the cast and about 15 hours to print test model for real-life testing.



Figure 4.3 SLA printed test tube

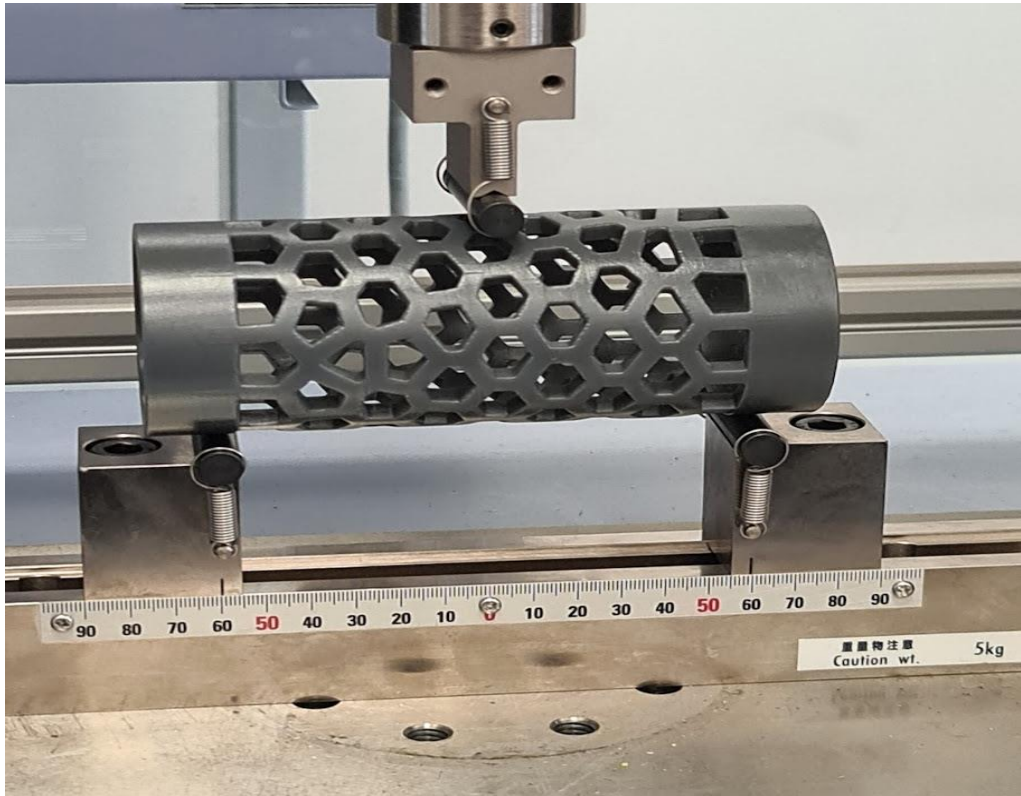


Figure 4.4 3D Printed arm cast

The 3D printed arm (Figure 4.4) cast was printed along with the test tube but is made of cheap plastic instead and it is only meant for display.

4.2 Real-life testing

The objective of this test is to compare the real-life result with the result from simulations to see how accurate are the simulations. There were only one test tube because the price to print it with T1500 resin is quite high, the price for a 150mm long, 60mm in diameter, and 5mm thick tube cost about 30 USD. The testing method was 3-point bend test using a AGXTM-V2 testing machine, made by Shimadzu.



 *Figure 4.5 Before testing*
Vietnamese-German University

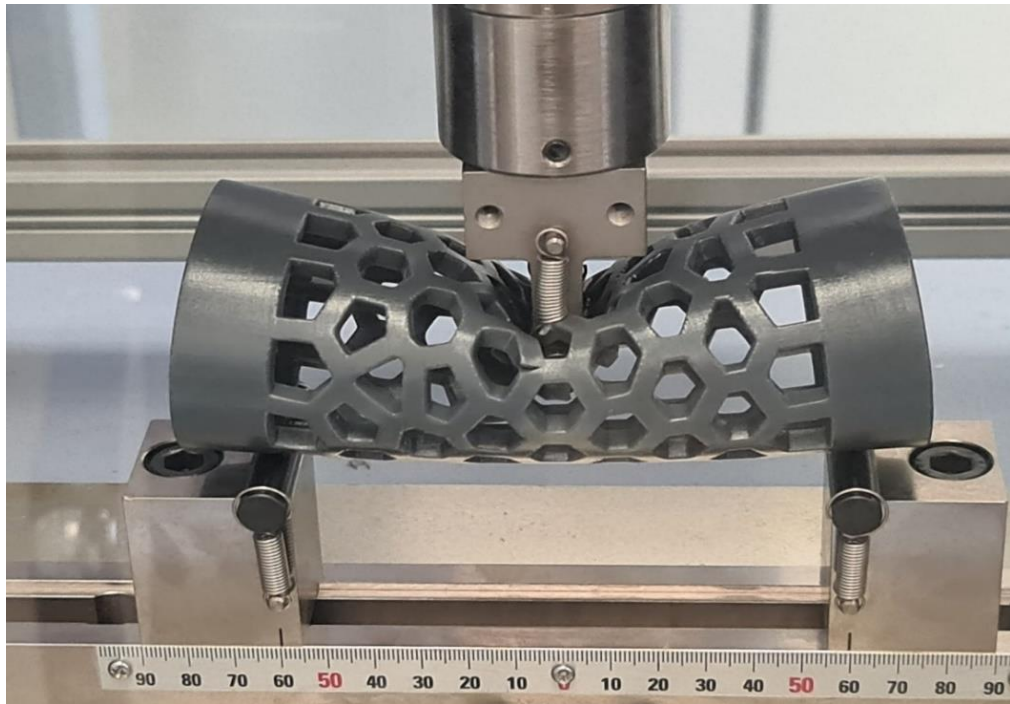


Figure 4.6 After testing

The test tube then begins to spring back to its original form. After about 10 minutes from the test, the tube is back to its original shape with some permanent deformities. In Figure 4.7, we can see that a broken small part, it is where the force applies on the tube.



Figure 4.7 Some time after the test

4.3 Result discussion

From the graph in Figure 4.8, we can see that the test tube begins yielding when the applied force reaches 600N, 850N is when the part where the force was applied crack. To my surprise, the model continues to endure up to 1240N before it finally breaks. For ease of analyzing, only the data below 600N threshold were accounted.

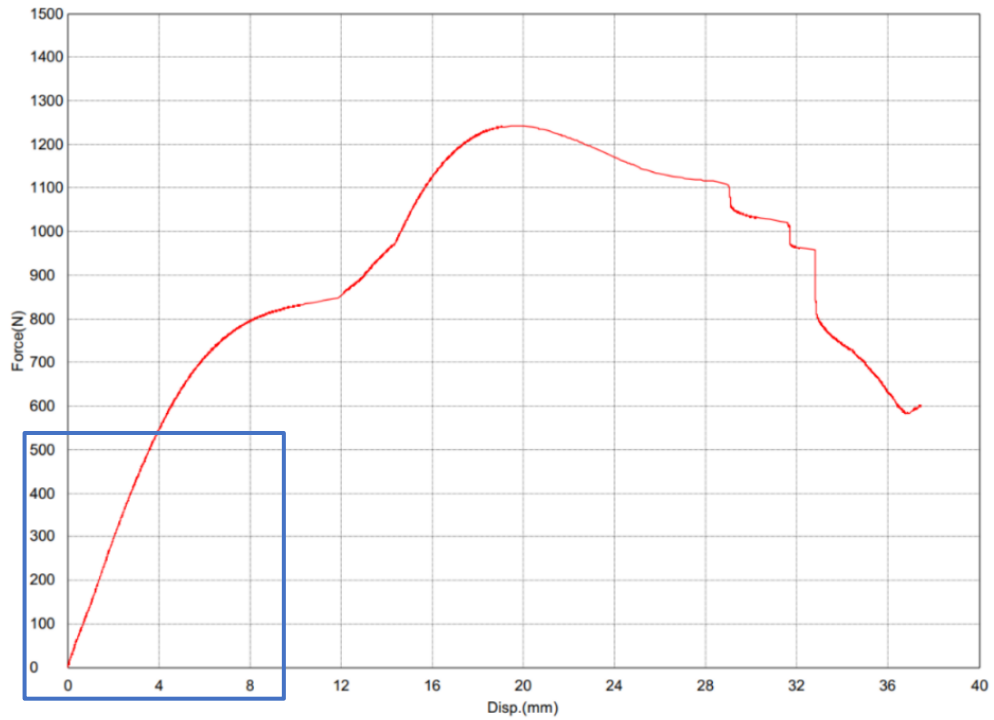


Figure 4.8 Results from 3-points testing

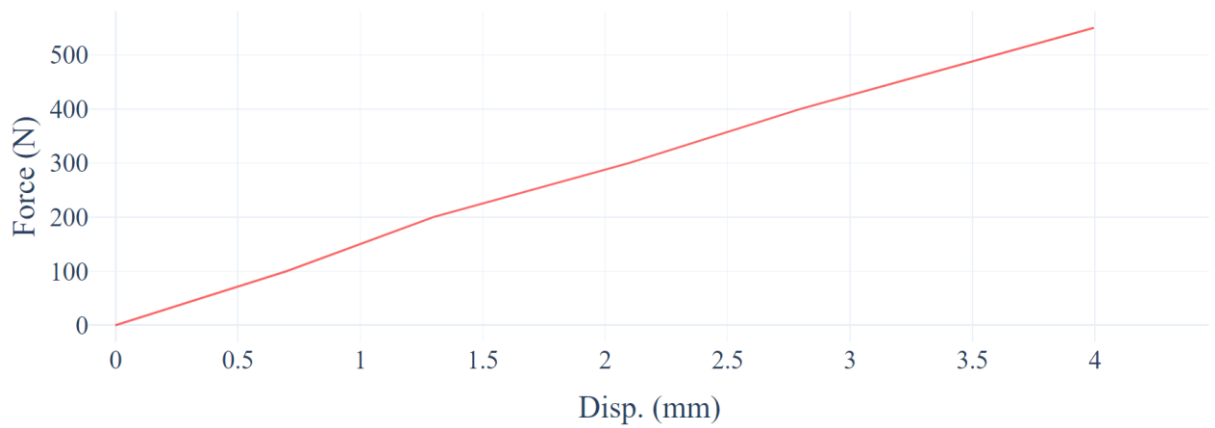


Figure 4.9 Zoomed-in chart

As seen in Figure 4.9, the tube deforms 4mm when the applied force approaching 550N but the result from the simulation Figure 4.10 show that the tube would only deform about 2mm when given the same force. After making some adjustment to the tensile

modulus of material in the simulation, the tube deforms 4mm when the modulus is about 0.8 GPa.

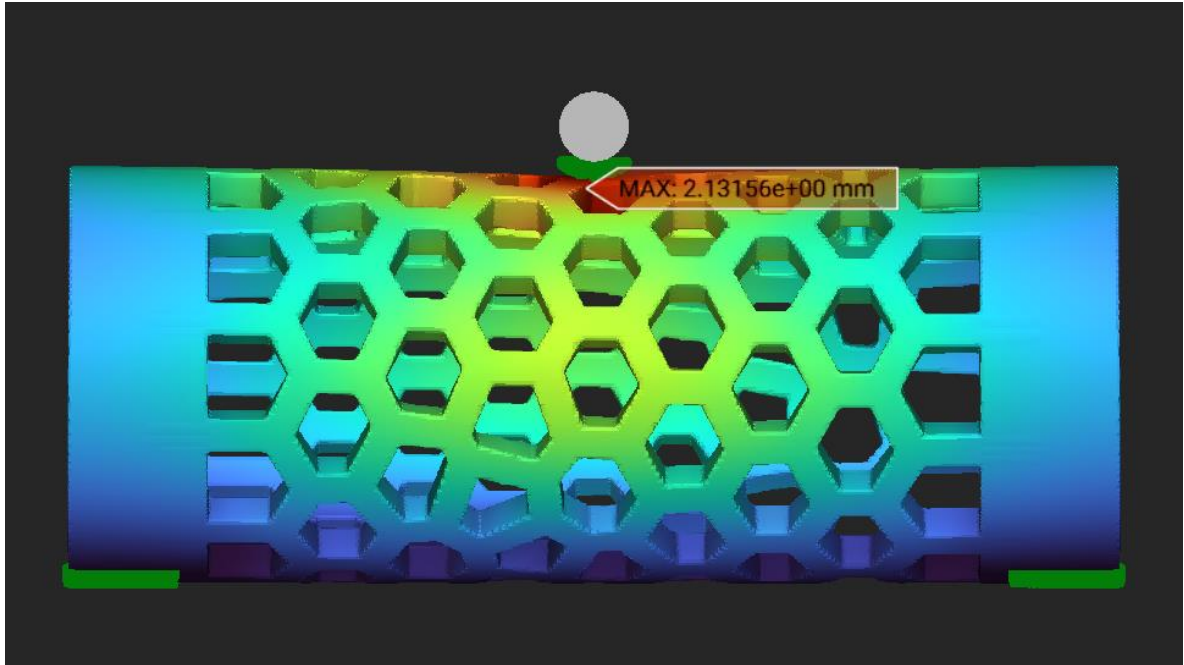


Figure 4.10 Simulation of test tube
Vietnamese-German University

Resin quality degrades over time, and humidity can affect the mechanical properties of 3D resin prints heavily. The explanation to why the T1500 material degraded so much is that the print may have been left overnight without being cured, since printing the tube model takes 15 hours. The final result was only 53% of the expected quality, unfortunately.

Generally, the moisture and temperature will impact your 3D printed objects tensile strength, elasticity, toughness, ductility, and resilience [Rob-23]. However, if a 3D resin print has been cured with UV, then humidity will not impact the model, irrespective of how wet it is.

With the new tensile modulus, the arm cast model in simulation would deform about 3.6mm when we apply 1000N around a wide area of the wrist. This much deformation can deter the patient's healing process, the ideal deformation should less than 1mm.

However, the problem can be easily fixed by increasing the amount of lattice on the cast, or we can focus the lattice pattern to where the force is applied. With the program ready to make adjustment to the cast at any time this process would only take about 30 minutes at best. This opens up the possibility to also accept customization from the customers.



5 Review, recommendation, and conclusion

5.1 Review and recommendation

The aim of this project is to study and create a 3D printed cast as another treatment for bone fracture that improve the patient's comfort and hygiene. However, there were some obstacles in the process of making the cast that I want to address and recommend some method I used.

First of all, a 3D scanned model of an arm was needed and I was lucky to be able to borrow a 3D scanner for it. There are many free app that provide 3D scanning, but most of them fail to entirely capture an object's dimension. The only method I have some success in and what I would recommend is photogrammetry; this method require a good camera, which every phone nowadays have. The software used to process pictures into 3D model was 3DF Zephyr, it was good, easy to use, and free.

Secondly, the software I would recommend using to process 3D model into a cast is nTopology. The software is free for students and currently the only program I know that can modify a 3D model easily if you spend some time learning it. The nTopology software's selling point is that all the codes and commands are condenses into blocks, which contain functions that operate based on given inputs from the user.

Despite the ease of use, nTop software require a very steep learning curve as you need to learn how each block interact with one another. There is so much to the software that it is hard to know where to start. Some of the features are difficult to find if you don't know which block to use. The process of coding was very time consuming, and the software needs so many blocks to work that it took me 3 weeks to complete coding for the cast. However, after the program have been completed it is very easy to modify your model, any changes required only a few inputs or a click and drag of the mouse.

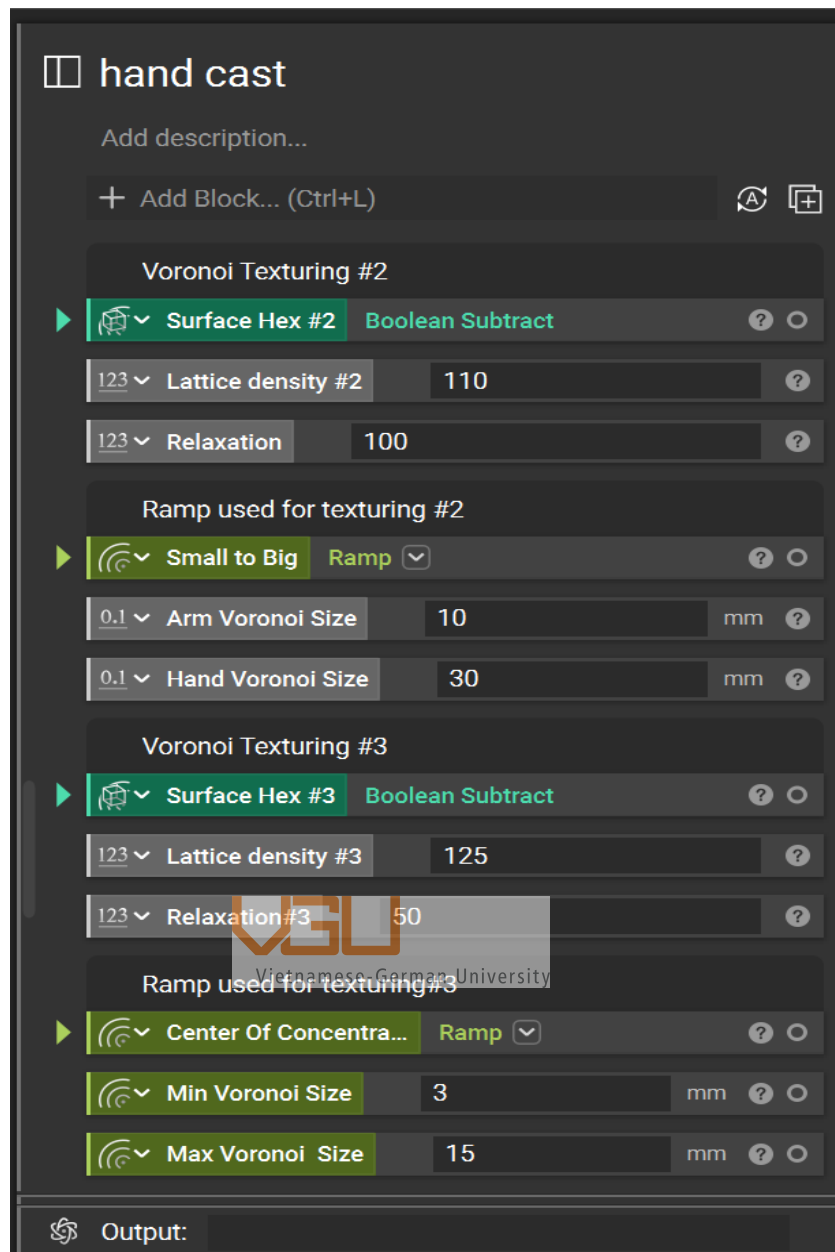


Figure 5.1 Block coding of nTopology

Furthermore, I would recommend reconstructing the 3D model in a CAD software first and then use nTop, since some better programming block in nTop require a CAD model instead.

Finally, an important thing is to ask and prepare test models to test your cast, the printing time for each model takes a whole day so it is best prepared in advance so that you can get more than just one real-life test.

5.2 Conclusion

3D printing and nTopology program are two innovative technologies that are transforming the manufacturing industry. 3D printing allows for the creation of complex and intricate patterns for any medical device by building up layers of material. While nTop provides advanced capabilities for designing and optimizing these designs, it is also capable of processing any models by reusing the coding that was used for the first models. Together, they are a powerful toolset for engineers, designers, and manufacturers to create highly optimized, lightweight parts with intricate shapes and features.

Overall, the combination of 3D printing and nTopology program offers tremendous potential for advanced manufacturing, enabling the creation of highly customized and optimized parts that were previously impossible to manufacture with traditional methods. As these technologies continue to evolve and become more accessible, we can expect to see even more innovative and ground-breaking applications in the medicine field, such as aerospace, and automotive engineering.



Vietnamese-German University

6 References

[Chen-2017] Chen, Y; Lin, H; Zhang, X; Huang, W; Shi, L; Wang, D: Application of 3D-printed and patient specific cast for the treatment of distal radius fractures: initial experience, *3D Print Med*, Vol.8, 2017

[Dino-13] Heinrich Mallison.: Photogrammetry tutorial 3: turntables. *Dinosaurpalaeo*, 2013

URL: <https://dinosaurpalaeo.wordpress.com/2013/12/20/photogrammetry-tutorial-3-turntables/>, last access: 27/2/2023

[Form-2021] Formlabs (Publ.): Tough 1500 material catalog, 2021

URL: <https://formlabs-media.formlabs.com/datasheets/2001292-TDS-ENUS-0.pdf>, last access: 27/2/2023

[LANCET-2021] THE LANCET (Publ.): Found in “Global, regional, and national burden of bone fractures in 204 countries and territories, 1990–2019: a systematic analysis from the Global Burden of Disease Study 2019”. THE LANCET, 2021

URL: [https://www.thelancet.com/journals/lanhl/article/PIIS2666-7568\(21\)00172-0/fulltext#seccestitle150](https://www.thelancet.com/journals/lanhl/article/PIIS2666-7568(21)00172-0/fulltext#seccestitle150), last access 26/02/2023

[Liz-13] Liz Stinton.: This 3D printed cast could be the future of healing broken bones. *Wired*, 2013

URL: <https://www.wired.co.uk/article/3d-printed-cast> , last access 28/2/2023

[OSU-16] Ohio State University (Publ.): Arm Injury Statistic, 2016

URL: <https://u.osu.edu/productdesigngroup3/sample-page/>, last access 28/02/2023

[Rob-23] Rob.: Does Humidity Affect Resin 3D Printing?. 3Dprintscape, 2023

URL: <https://3dprintscape.com/does-humidity-affect-resin-3d-printing/>, last access: 28/2/2023

[TMF-20] The Medical Futurist (Publ.): Found in “Where Are 3D-Printed Casts?”, The Medical Futurist, 2020

URL: <https://medicalfuturist.com/where-are-3d-printed-casts/>, last access 28/02/2023

[Wald-2021] Waldburger, L; Schaller, R; Furthmüller, C; Schrepfer, L; Schaefer, D; Kaempfen, A: 3D Printed Hand Splints versus Thermoplastic Splints: A Randomized Controlled Pilot feasibility Trial. *International Journal of Bioprinting*, Vol.8, 2021

