Design, Analysis and Fabrication of Dynamic Hand Splint Using Reverse Engineering and 3D Printing

Submitted by

HAMAD EJAZ

MUHAMMAD BILAL

MUHAMMAD FAWAD

RAHEEL AHMAD

Supervisor

DR. TUFAIL HABIB

DEPARTMENT OF INDUSTRIAL ENGINEERING

UNIVERSITY OF ENGINEERING AND TECHNOLOGY

PESHAWAR, PAKISTAN

Session: 2019-2023

Executive Summary

The UET Peshawar and paraplegic center Peshawar (PCP), collaborated to design an assistive device (dynamic hand splint) for disable people having nerve palsy using additive manufacturing techniques. By combining Additive Manufacturing (AM), creative trim line arrangements, and the principles of reverse engineering, this research establishes a ground-breaking paradigm for the creation of assistive devices. The project, which is focused on creating a customized Dynamic Hand Splint, uses AM's Fused Deposition Modelling (FDM) method together with various trim line forms to enhance personalization, effectiveness, and quality. The splint has remarkable stress and strain capacities due to the use of Finite Element Analysis (FEA). A perfect fit and unmatched comfort are achieved through exact customization made possible by 3D scanning technology and CAD software. The end result of this innovation is a splint that not only exhibits increased aesthetics but also highlights sustainability by reducing material waste. This design epitomizes cost-effectiveness with features that cater to different damage levels. In addition to making it simple to wear, the lightweight design encourages airflow, avoiding any potential discomfort. This project shows the power of cutting-edge technologies as well as how the fusion of creative design and reverse engineering may revolutionize assistive technology, greatly enhancing the quality of life for people with specific requirements.

Abstract

In the current dynamic and competitive manufacturing landscape, integrating advanced technology has become essential for companies to meet customer demands in terms of time, cost, customization, and quality. Additive Manufacturing (AM) technology has been rapidly advancing and is gradually replacing traditional manufacturing methods. AM allows for intricate designs and enables the production of complex, customized parts with remarkable accuracy. In the context of developing a Dynamic Hand Splint using Additive Manufacturing (AM) technology, reverse engineering plays a crucial role in the scanning and design process. Reverse engineering involves the process of capturing the geometry and dimensions of an existing object to recreate it digitally. In the case of assistive devices like the Dynamic Hand Splint, reverse engineering allows for the customization of the device to fit the specific needs of the disabled individual. The first step in the reverse engineering process would be to scan the hand of the disabled individual. This can be achieved using 3D scanning technologies such as laser scanners or structured light scanners. The scanning process captures the external surface of the hand, creating a detailed and accurate 3D model of its unique shape and contours. Once the hand is scanned and the 3D model is generated, it serves as the basis for designing the personalized Dynamic Hand Splint. The designers can then use Computer-Aided Design (CAD) software to manipulate and optimize the splint's design according to the specific requirements of the individual's hand. During the design phase, considerations are made for the three different trimline options—elliptical, triangular, and elliptical mesh—as well as the choice of materials such as ABS, Nylon, and Polypropylene. The scanned 3D model of the hand allows for precise adjustments and customization of the splint, ensuring a comfortable fit and effective support. Finite Element Analysis (FEA) is then conducted on the CAD model of the Dynamic Hand Splint. FEA is a simulation technique used to analyze how the device behaves under different loading conditions, identifying stress points, strain characteristics, and safety margins. This analysis helps in refining the design, ensuring that it meets safety and performance standards. Once the optimal design is determined through FEA and statistical analysis using general factorial design, the 3D printing process using Fused Deposition Modeling (FDM) can be initiated. PLA material is used for the initial prototype to demonstrate the practical implementation of the design and ensure that all functional and ergonomic requirements are met. By leveraging the capabilities of AM technology and integrating reverse engineering techniques, the project can successfully develop and manufacture personalized assistive devices like the Dynamic Hand Splint. This approach significantly improves the customization options, reduces lead times, and enhances the overall quality of life for disabled individuals by providing them with tailor-made solutions that cater specifically to their unique needs.

Keywords: Dynamic Hand Splint, finite element analysis, Additive manufacturing, Fused deposition modeling, PLA material.

Table of Contents

List of Figures

List of Tables

List of Acronyms

DHS	Rapid prototyping
CAD	Computer Aided Design
3D	Three Dimensional
AD	Additive Manufacturing
STL	Stereo-lithography
LOM	Laminated Object Manufacturing
SLS	Selective Laser Sintering
FDM	Fused Deposition Modeling
PLA	Poly-Lactic Acid
ABS	Acrylonitrile Butadiene Styrene
DAM	Design for Additive Manufacturing
IM	Injection Molding
RM	Rapid Manufacturing
FFF	Fused Filament Fabrication
FEA	Finite Element Analysis
FEM	Finite Element Method
SAM	Sustainability of Additive Manufacturing

INTRODUCTION

Assistive devices, also called mobility aids, empower individuals with disabilities, body deformities, or age-related limitations to lead more independent lives. These tools assist people in performing daily tasks, fostering their integration into society. A wide array of assistive devices exists, ranging from prosthetic and orthotic devices to aids for vision and hearing impairments. These technological innovations enhance the lives of individuals with physical challenges by promoting autonomy and well-being.

A subset of assistive devices is orthotic and prosthetic devices. Orthotics aid in injury recovery, supporting and optimizing the function of injured body parts. Prosthetics, on the other hand, replace missing or damaged body parts, restoring mobility and functionality. An example of a common condition necessitating an assistive device is radial nerve palsy, which causes wrist drop. To aid in recovery from this condition, a dynamic hand splint is utilized. This splint connects the fingers and wrist, enabling movement exercises that gradually reactivate the radial nerves and restore function.

However, existing splint designs often lack aesthetic appeal. To address this, a more innovative and visually pleasing design was developed through brainstorming and group discussions. Structural and stress analyses were conducted to ensure the new design's functionality. The next steps involve refining the design for increased patient comfort and conducting thorough stress and structural analyses for optimal effectiveness in treating wrist drop. Additionally, selecting appropriate materials and exploring alternative manufacturing methods, such as 3D printing, are being pursued to enhance cost-effectiveness and production efficiency.

Finite Element Analysis (FEA) was applied to assess the dynamic hand splint's stress distribution and strain characteristics across different materials. This analysis revealed that Nylon exhibits the highest stress and strain bearing capability, making it an optimal material choice. In comparison to traditional manufacturing techniques like injection molding, additive manufacturing, or 3D printing, offers advantages in terms of customization, speed, and cost-effectiveness.

This research contributes significantly to academia by introducing an innovative dynamic hand splint design that employs thera-bands for enhanced functionality and recovery from radial nerve palsy. Moreover, the utilization of Finite Element Analysis for dynamic hand splints' performance assessment is a unique and valuable addition to the academic discourse. Practical significance lies in the project's focus on improving the lives of individuals with radial nerve injuries at the Paraplegic Center Peshawar, offering a tailored solution that addresses a specific need. This research not only advances academic knowledge but also positively impacts individuals' quality of life.

RESEARCH METHODOLOGY

This chapter presents a comprehensive overview of the methodology employed to successfully complete our project. It offers a clear and sequential delineation of the methodology's content, including detailed definitions and explanations. To ensure the project's smooth execution, a flowchart has been created, outlining all the necessary steps. The subsequent sections provide a thorough explanation of each step, presenting a step-by-step procedure for the project's implementation.

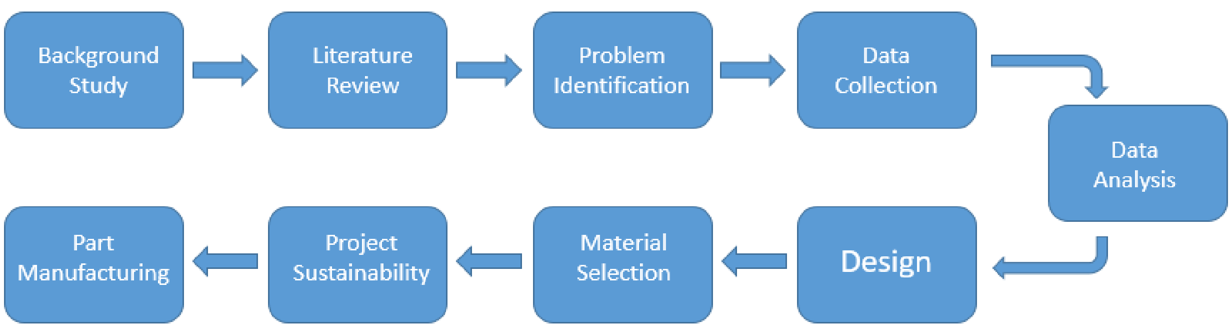

Figure 1 Steps used in research methodology

Literature Review

This literature study focuses on various topics including radial nerve palsy, reverse engineering, design, analysis, 3D printing, Additive Manufacturing, Customization, and Dynamic Hand Splint. It provides an in-depth exploration of these subjects within its scope. Furthermore, the study offers detailed explanations of various tools and procedures employed in additive manufacturing.

Problem Identification

Radial Nerve Palsy is the impairment of the radial nerves in the hand then wrist drop occurs. In this injury patient cannot move his hand and specially cannot move the wrist. Dynamic hand splint is one of the solution for radial nerve impairment. In the existing design of Dynamic Hand Splint the springs are being used that are not suitable for the patients and the design is not customized. A better design is required to address the above issues.

Part Selection

The chosen component for data collection is the Dynamic Hand Splint. This externally applied assistive device plays a crucial role in managing ankle motion, mitigating the impact of muscle weakness, improving the gait pattern, enhancing walking efficiency, and providing support and balance to individuals with disabilities.

Data Collection

Samples of Dynamic Hand Splint from various age groups were gathered from the Paraplegic Center Peshawar for analysis. The dimensions of these samples were carefully examined. The data collection process involved using specific instruments, which are thoroughly described in Chapter 04, titled "Data Collection."

Part Design and Data Analysis

This section provides a comprehensive explanation of the modeling and analysis procedures conducted in Fusion 360. By utilizing the Fusion 360 program, we were able to create a detailed model and perform structural analysis on the assistive component, specifically the Dynamic Hand Splint. This analysis aimed to assess the behavior of the splint under real-world conditions, taking into account realistic forces and stresses. Notably, the structural analysis was carried out using the same software used for the part's initial creation.

Material Selection

During the material selection process for 3D printing, considerations were given to various options including nylon, ABS, and polypropylene. After careful analysis, it was determined that nylon was the most suitable choice for the project. Nylon offers a combination of desirable properties such as excellent strength, durability, and flexibility, making it well-suited for the production of the 3D printed component. Its high impact resistance and ability to withstand various environmental conditions further supported the decision. Ultimately, the selection of nylon as the material for 3D printing was based on its compatibility with the project's requirements and its ability to deliver optimal performance in real-world applications.

Project sustainability

The project's sustainability aspect is a crucial consideration when utilizing 3D printing for the production of the Dynamic Hand Splint with the chosen materials: nylon, ABS, and polypropylene. We are targeting 3 SDGs in the project these are SDGs number 3, 9, and 12. Sustainability is promoted through several key factors. Firstly, 3D printing allows for on-demand manufacturing, minimizing waste by only producing the required number of splints. Secondly, the chosen materials have their own sustainability benefits. Nylon, for instance, offers excellent durability, reducing the need for frequent replacements. ABS is known for its recyclability, allowing for the potential reuse of materials. Polypropylene, on the other hand, possesses a lower environmental impact due to its energy-efficient production process. By incorporating these sustainable practices and materials, the project aims to contribute to a more environmentally friendly and resource-efficient approach to assistive device production.

Part Manufacturing

This section of the paper centers on the manufacturing process of the Dynamic Hand Splint through 3D printing. Within this chapter, you will gain insight into the specifications of the 3D printer employed. Furthermore, it provides a thorough examination of the 3D printing software and the specific printing technique employed. To create a scaled-down version of the Dynamic Hand Splint, the chosen material is nylon, utilizing elliptical Mesh Trim-lines for the manufacturing process.

Project Flow Chart

Figure below illustrates the flow diagram, showcasing the sequential workflow of the project. The flow chart encompasses various stages, including problem identification, project selection, data collection, analysis, as well as the design, analysis, and manufacture of the part. It provides a clear visualization of the step-by-step progression of the project.

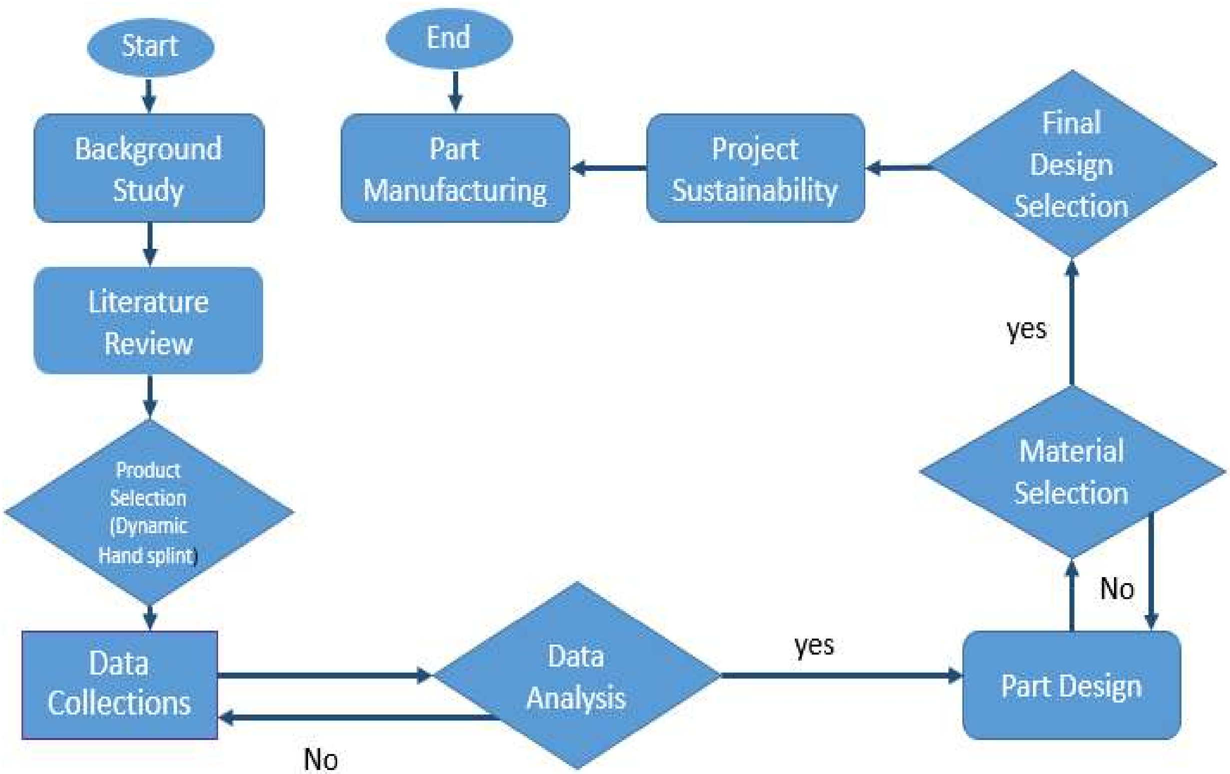

Figure 2 Project flow chart

Summary

This chapter comprehensively discusses the project's methodology, providing a clear definition and explanation of the research methodology. The content of the methodology is presented in a sequential manner at the start of the chapter. To ensure the project's successful completion, a flowchart is included, depicting all the necessary actions and steps involved in the project

DATA COLLECTION AT PARAPLEGIC CENTER PESHAWAR

This chapter encompasses various aspects essential for the design analysis of the assistive Dynamic Hand Splint, including the methodology of data collection and the properties of the collected data. It also details the sample used for data collection and elucidates the diverse measuring strategies employed to extract information from the sample. By covering these elements, the chapter provides a comprehensive understanding of the data collection process and its relevance to the overall analysis of the Dynamic Hand Splint design.

Data Collection Method

Data collection was initiated at the Paraplegic Center Peshawar, where samples of Dynamic Hand Splint from diverse age groups were gathered for evaluation of their structural and dimensional characteristics. Precise measurements of the dimensions were obtained using Vernier Caliper and Measuring Tape. Each DHS sample underwent individual analysis, allowing for a thorough examination of their specific attributes.

Dynamic Hand Splint

Our project concerns the Dynamic Hand Splint (DHS), which is an aid for controlling rotational motion and stabilizing joints in the hand of disabled people with a kind of neurological or any other weakness problem known as radial nerve palsy. Below (Fig 4.1) shows sample of Dynamic hand splint.

Figure 3 Present Dynamic Hand Splint

Instruments Used for Data Collection

With the use of the following instruments, the dimensions of the Dynamic Hand Splint (DHS) were determined to be as follows:

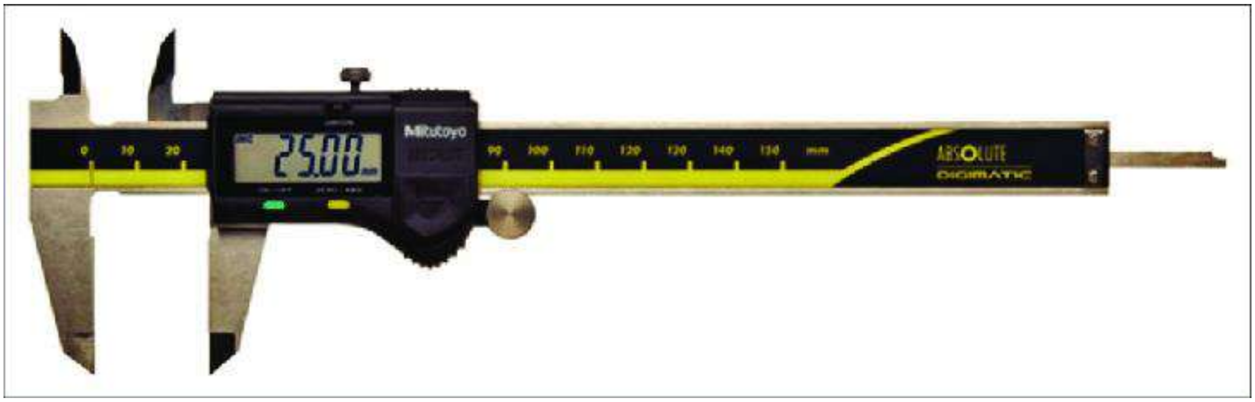

Figure 4 Vernier Caliper

Figure 5 Measuring Tape

Data Collection Procedure

The measurements are taken through the following steps:

A Vernier Caliper is used to measure the Dynamic Hand Splint (DHS) internally and externally and also the diameter of the semi-circle.

Figure 6 Internal & External diameter measurement

Similarly, a measuring Tape was used to find the length, width and depth of the different sizes of Dynamic Hand Splint.

Basic Measurements

Below mentioned in the table 1 are the measurements of the Dynamic Hand Splint, which are taken in the Metrology Laboratory during the data collection process.

Table 1 Summary of measurements

	Thickness (mm)			Diameter (mm)			Vertical Depth (mm)			Length (mm)	
Age Groups (Yrs)	Front End	Middle	Back End	Front End	Middle	Back End	Front End	Middle	Back End	Front End to Wrist	Wrist to Back End
12 to 18	1.72	2.01	2.12	28.28	29.32	35.76	27.17	25.93	35.45	74	122
19 to 24	2.21	2.52	2.61	63.21	44.67	57.87	43.48	41.48	56.73	118	195
25 to 40	2.87	3.15	3.29	74.23	55.54	72.57	54.35	51.85	70.91	148	244

Detailed dimensions of the Dynamic Hand Splint are shown below in figure.

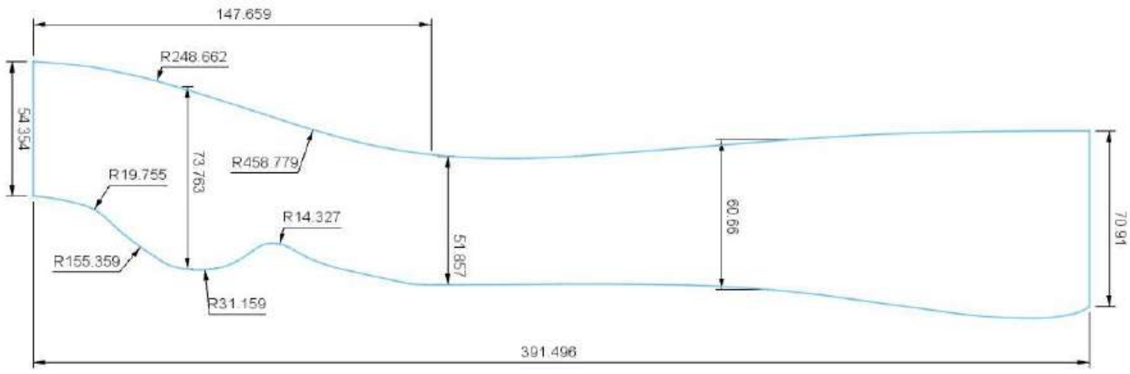

Figure 7 Dimensions of Dynamic Hand Splint samples

Thera Bands alos known as resistance bands or exercise bands, are sometimes used in hand splint design for specific therapeutic purposes. The primary purpose of using these bands into hand splints is to provide resistance based excercises and rehabilitation for the hand and wrist. Thera Bands are used in splint design having diferent strenghts and elongations. Data about the thera bands has been obtianed from Paraplegic center pehsawar (PCP).The yellow bands are categorized as offering light resistance. This implies that they possess high stretchability and require minimal effort to extend and stretch. These therabands are particularly beneficial for exercises targeting areas such as shoulders and shins, where a small amount of resistance is sufficient to engage and activate the muscles effectively. The red upto blue follows the trend for more strenght of the muscles. Detailed data for thera bands used for the Dynamic Hand Splint are shown below in figure.

Table 2 Details of Thera-Bands

Thera Band Color	Strength (Resistance in Kg)	100% Elongation
Thera Band Yellow	0.44-2.64 kg of Resistance (Lightest)	2.6
Thera Band Red	0.88-3.08 kg of Resistance (Light)	2.1
Thera Band Green	0.88-4.4 Kg of Resistance (Light Medium)	1.7
Thera Band Blue	1.32-6.16 kg of Resistance (Medium)	1.3

Reverse Engineering of a Human Hand by 3D SCANNING

Objectives

- To know about reverse engineering in design and know about 3D scanning.
- To make customized designs of dynamic hand splints by reverse engineering.

- To know the benefits of making designs by reverse engineering as compare to make designs by traditional method.

This chapter contains information about reverse engineering in design and gives information about 3D scanning by device XBOX KINECT. And in last of this chapter there will be a comparison between customized designs by reverse engineering and designs by traditional method.

Reverse Engineering

Reverse engineering in design is the process of closely examining and deconstructing an already existing product to gain a deeper understanding of its design and engineering principles. This allows designers to extract valuable information that can be utilized to develop new products with similar features or enhance existing designs.

The process of reverse engineering in design often involves the use of advanced tools such as 3D scanners and specialized software. These tools enable designers to capture and analyze both the physical and digital components of the product. By gathering this data, they can create detailed 3D models and engineering specifications that serve as the foundation for creating new products or improving existing ones.

Reverse engineering in design plays a crucial role in industries like manufacturing, where the ability to replicate products with similar functionality or design can provide a competitive edge. It also allows designers to identify areas for improvement in existing designs, such as optimizing material usage, enhancing efficiency, or boosting performance.

In our specific project, we are employing reverse engineering to develop customized dynamic hand splints. Instead of relying solely on existing parts, we directly scan human hands to obtain precise dimensions. Through the use of software, we finalize the designs of these customized hand splints, ensuring a perfect fit and optimal functionality.

Figure 8 Reverse Engineering Process

Xbox Kinect Sensor

The Xbox Kinect Sensor is a device initially created for the Xbox 360 gaming console. It utilizes cameras and infrared sensors to detect and monitor the movements and gestures of players, enabling them to interact with games without a traditional controller.

The Kinect Sensor consists of a depth sensor, RGB camera, and multi-array microphone that work together to capture the motions and voices of players. By utilizing infrared light, it generates a 3D map of the surroundings and tracks the players' positions within that environment. This data is then utilized to control games and other applications.

Aside from gaming, the Kinect Sensor has found applications in various industries and fields, including healthcare, education, and robotics. Its ability to track movements and gestures has been utilized in physical therapy, educational tools, and research endeavors, among other areas.

While Microsoft has discontinued the production of Kinect sensors, its technology and features have been incorporated into other Microsoft products and applications, such as the Microsoft HoloLens and Windows Hello. This allows for continued exploration and utilization of the innovative capabilities offered by the Kinect Sensor's tracking and sensing abilities.

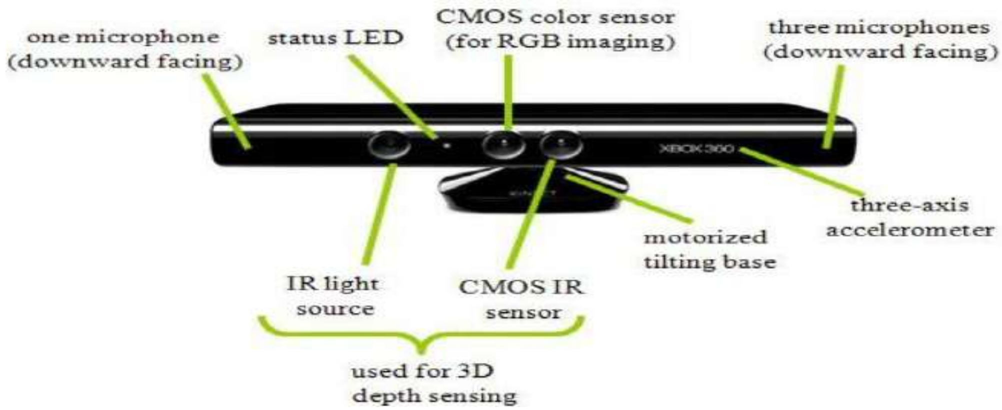

Figure 9 Xbox Kinect used for 3D Scanning

3D Scanning in Reverse Engineering

3D scanning plays a vital role in reverse engineering by providing a valuable solution for accurately replicating complex or irregularly shaped objects. Traditional measurement techniques may not be practical or precise enough to capture the intricate details of such objects. Through the process of 3D scanning, engineers and designers can capture the precise dimensions and geometry of the object, creating a digital model using computer-aided design (CAD) software. This digital model can then be modified, improved, or used for various applications.

3D scanning involves the use of specialized hardware and software to capture three-dimensional data of real-world objects or environments. The technology works by capturing data points from the surface of the object, including its shape, size, texture, and color. These data points are then processed to create a digital replica or model that closely represents the physical object. This digital model can be further analyzed, modified, or used for various purposes, such as product development, quality control, visualization, or preservation of cultural artifacts.

The advantages of 3D scanning in reverse engineering are significant. It allows for precise measurements and accurate representation of intricate details that may be challenging to achieve through traditional methods. It also enables engineers and designers to work with complex geometries and create digital models that can be easily modified or customized. Additionally, 3D scanning reduces the need for physical prototypes and facilitates more efficient design iterations.

Figure 10 Reverse Engineering in Creating Design

There are various methods of 3D scanning, such as structured light scanning, laser scanning, photogrammetry, and CT scanning. Each method has its own advantages and limitations depending on the application and the object being scanned.

3D scanning finds applications in different industries like product design, engineering, manufacturing, healthcare, entertainment, and cultural heritage preservation. It allows designers and engineers to create accurate and detailed models of physical objects for prototyping, testing, and simulation. In the medical field, it helps in creating precise digital models of patients' bodies for diagnosis, treatment planning, and surgical simulation.

In our project, we are using the XBOX Kinect device to capture images of human hands. The device utilizes infrared rays for scanning and captures all the dimensions of the hand, which are displayed on the screen. We use KSCAN 3D Software along with the XBOX Kinect to view the scanned images. After obtaining the images, we use CAD software to finalize the desired design.

Overall, 3D scanning technology has brought a significant transformation in how we capture and interact with the physical world. It opens up new possibilities for innovation and creativity across various fields.

Figure 11 Scan Image of a human hand using Xbox Kinect

3D Scanning Technologies

Below are some key 3D scanning technologies and a brief description of each:

Photogrammetry: Photogrammetry is a technique where multiple photos of an object are taken from various angles. Special software is then used to combine these images and create a 3D model. It is commonly used to create digital models of structures like buildings, landscapes, and other large objects.

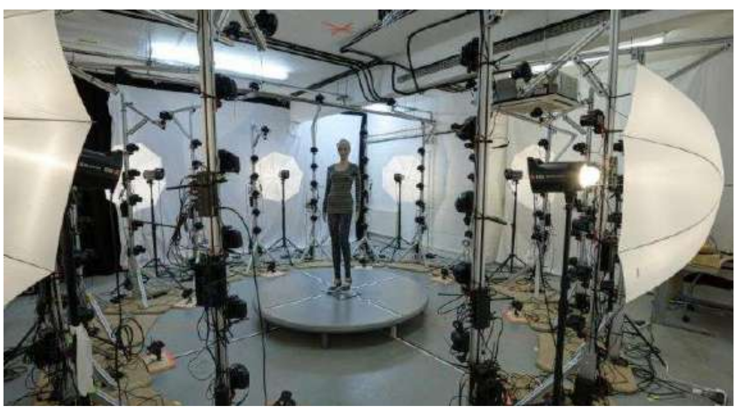

Figure 12 Photogrammetry Process By 3D Scanning (ljmu research, artstation)

Structured Light Scanning: It is a method that uses projected light patterns and sensors to capture the shape of an object. The scanner analyzes how the pattern is changed by the object's contours to create a 3D model. This technology is commonly employed in industrial settings for various applications.

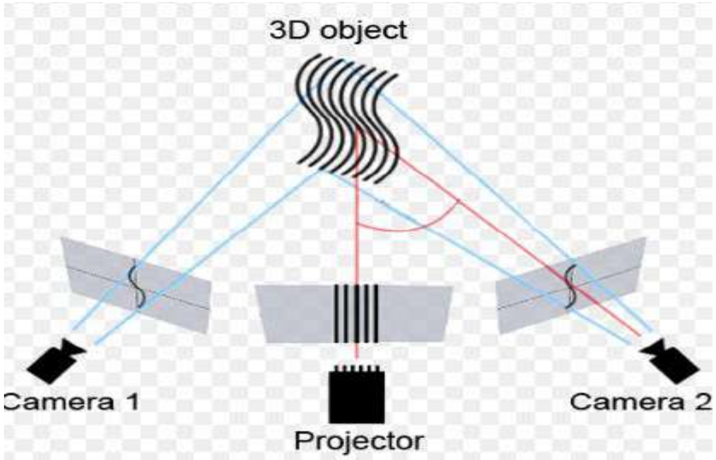

Figure 13 Structured Light Scanning Process (ljmu research, artstation)

Laser Scanning: It is a method that uses a laser to measure the distance between a scanner and the surface of an object. The scanner rotates around the object, capturing data from different angles. This data is then used to create a detailed 3D model of the object. Laser scanning is widely applied in various industries like engineering, architecture, and manufacturing to create accurate digital models of objects and parts.

Figure 14 Handheld Blue Laser Scanning Captures 3D Metrology (FreeScan UE 3D Laser Scanner)

Time-of-Flight Scanning: It is a method that uses a light signal to measure the time it takes for the signal to return to the scanner. Based on this information, the scanner can create a 3D model of the object. This technology is commonly employed in fields like robotics and autonomous vehicles.

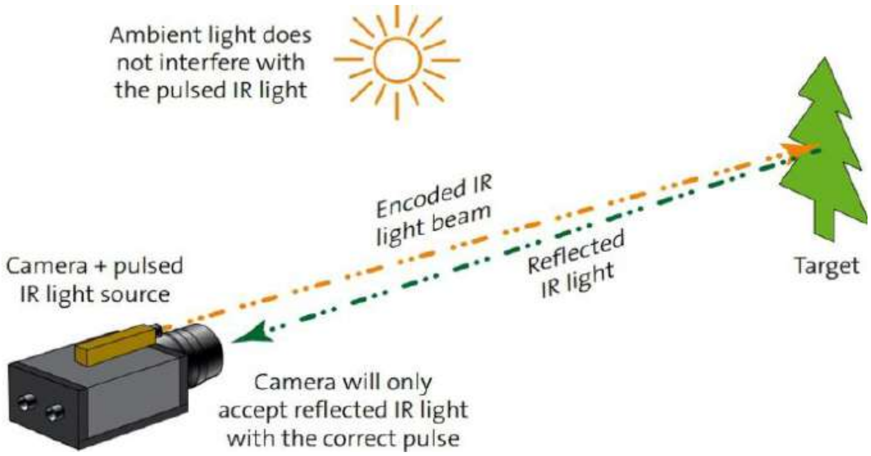

Figure 15 Time of Flight Scanning (Aaron Raymond See)

Contact Scanning: It is a technique where a scanner makes direct physical contact with an object to capture its shape and generate a 3D model. This method is commonly employed in manufacturing for quality control and inspection purposes.

Figure 16 Contact Scanning by 3D (wtidental.com)

Comparison between Reverse Engineering and Traditional Method of Making Designs:

Reverse engineering involves analyzing an existing product to understand its design and functionality, while traditional design refers to creating a new product from scratch. In traditional design, designers start with a blank slate and generate original ideas, whereas reverse engineering starts with an already existing product and focuses on understanding its design and how it works.

Traditional design methods can be time-consuming and costly since designers have to create the entire design from the ground up. On the other hand, reverse engineering can be faster and more cost-effective as designers already have a starting point and can concentrate on analyzing and comprehending the existing design.

Complex projects that require customization and creativity are better suited for traditional design methods. Reverse engineering is more suitable for products that are already well-defined and have a clear design.

When it comes to intellectual property, traditional design methods provide complete control over the design and intellectual property rights. Reverse engineering may raise ethical concerns if it involves unauthorized copying of an existing design.

Overall, traditional design methods are ideal for developing new and innovative products, while reverse engineering serves as a valuable tool for understanding existing designs and making improvements or modifications.

Summary

The main focus of this chapter was to gather and analyze data to assess its suitability for further research purposes. Initially, our primary objective was to collect essential information related to Dynamic Hand Splint (DHS) samples. This involved recording standardized measurements such as the person's weight, height, and dimensions of the DHS. Following the selection of the specific age group, a visit was made to the Paraplegic Center Peshawar, where various DHS samples were carefully chosen. These samples were then measured at the Metrology Lab using a combination of freehand sketching on white paper and detailed measurement techniques employing various measuring devices.

All the objectives are achieved at this stage. Introduction gives the information about reverse engineering that is the process of analyzing an existing product to understand how it works and how it was made. 3D scanning in reverse engineering explains diagrammatically that how to create design by using scanning device that is Xbox Kinect.

Comparison section explains the strengths and weaknesses of the designs by traditional method and the designs by reverse engineering. Overall, reverse engineering in design can be a valuable tool for companies looking to innovate and stay competitive in today's fast-paced business environment.

PRODUCT DESIGN AND ANALYSIS

This report section focuses on the design and analysis of a specific part. Detailed explanations of the modeling and analysis steps are provided in this chapter. The assistive part, known as the DYNAMIC HAND SLPINT, was created and analyzed using Fusion 360. The purpose of the structural analysis was to evaluate the performance of the product in real-world scenarios, considering actual forces and stresses it may encounter. Additionally, this chapter delves into the material properties of various polymeric materials utilized in the 3D printing process, with particular emphasis on PLA and ABS. A brief comparison of the mechanical properties between PLA and ABS is also included. It is important to note that the structural analysis was conducted within the Fusion 360 software, the same platform used for the part's design.

Product Design

To initiate the 3D printing process of the product, the design phase is undertaken. Typically, the 3D modeling design commences with a 2D sketch of the part, followed by solid modeling. Over the years, significant advancements have been made in 3D modeling software specifically tailored for 3D printing purposes. Among the extensively utilized 3D modeling software are:

- Autodesk Fusion 360
- ANSYS
- FREECAD
- MESHLAB
- CREO PARAMETRIC
- SOLIDWORKS

For the modeling and analysis of the assistive part (DYNAMIC HAND SLPINT), we opted to use Fusion 360. The subsequent section provides further details regarding the software and the approach employed for modeling.

Orthographic Projections

The front, side, and top view of the DYNAMIC HAND SLPINT is shown in figure below.

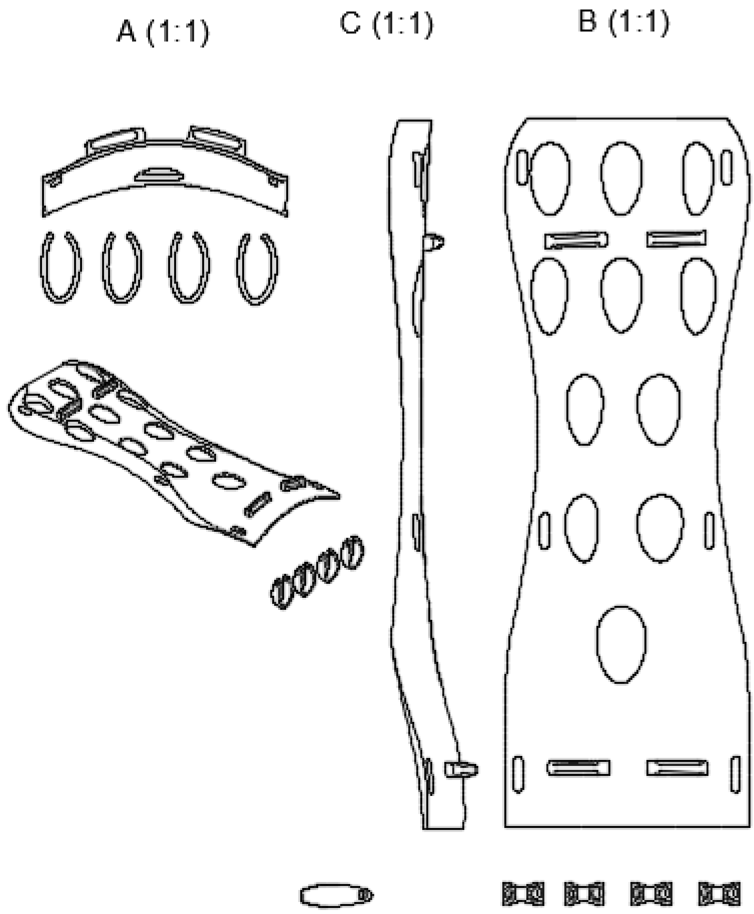

Figure 17 Different views of DYNAMIC HAND SLPINT

Material Selection

Fused deposition modeling (FDM) is predominantly utilized for manufacturing polymers, composites, and thermoplastics characterized by low melting points. However, achieving sustainable polymeric materials with enhanced mechanical properties is of utmost importance for FDM. The commonly used polymeric materials for 3D printing, such as ABS, nylon, and PLA, often fail to meet the necessary requirements. ABS exhibits competitive strength but emits an unpleasant odor during printing, while PLA is eco-friendly but possesses weaker mechanical properties.

Another material option with desirable properties is nylon, which is available in three different grades: nylon 6, nylon 6/6, and nylon 6/10. Nylon 6 exhibits superior impact strength and flex fatigue life compared to nylon 6/6, particularly under moist conditions. It can be processed at lower temperatures, possesses lower crystallinity resulting in reduced mold shrinkage and closer tolerances. On the other hand, nylon 6/10 demonstrates lower moisture absorption than nylon 6. It retains its toughness at low temperatures better than nylon 6 or nylon 6/6 and exhibits good resistance to most solvents and dilute mineral acids. After considering these properties, nylon 6 was chosen as the most suitable material due to its favorable mechanical properties and wide availability in the commercial market.

For the 3D printing of the DYNAMIC HAND SLPINT using FDM, we selected and analyzed PLA, nylon, and ABS. The advancements in manufacturing technologies aim to reduce costs and promote sustainable manufacturing. Ongoing research emphasizes the importance of eco-friendly manufacturing, minimizing emissions, and waste generation during the printing process. Additive manufacturing possesses a broad scope and vision to meet the requirements of environmentally friendly production.

Trimline Design

The trim-lines used in the upper limb orthosis, specifically the dynamic hand splint, play a crucial role in controlling its stiffness and flexibility. The amount of plastic trimmed around the ankle determines this. If the trim-lines have deep and sharp edges, they can result in significant stresses. On the other hand, trim-lines with rounded and angular geometries allow for a more even distribution of stress. In our research, all trim-lines have an area of 2047 mm2 and share a common center of gravity. Therefore, the only factor that affects the stiffness of the design is the shape of the trim-line.

To explore the impact of different trimline designs on stiffness and flexibility, we investigated four options: elliptical, triangular, and rectangular trimlines. We analyzed how each design influenced the overall properties of the orthosis, taking into account that all dimensions are measured in millimeters (mm).

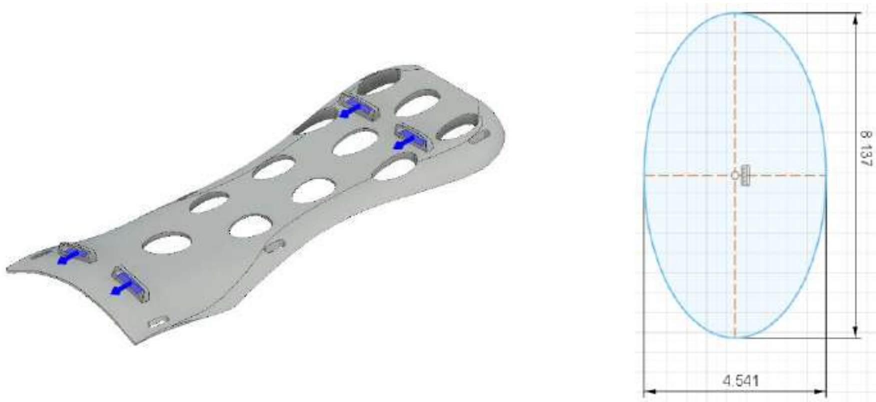

Figure 18 Elliptical trimline model and sketch profile

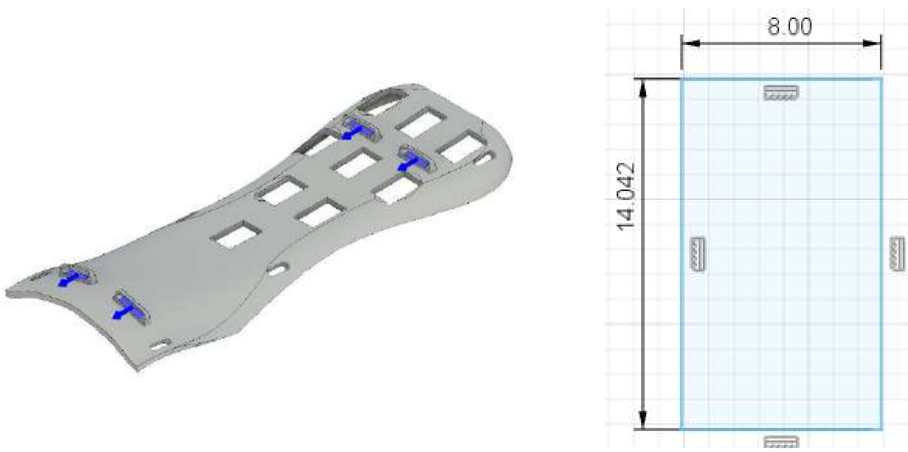

Figure 19 Rectangular trimline along with sketch profile

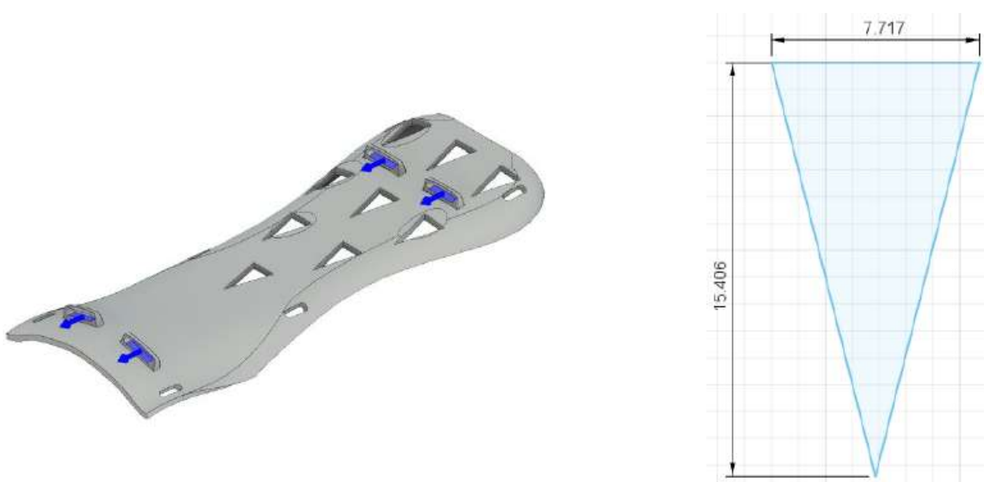

Figure 20 Triangular trimline along with sketch profile

Material Properties

Table 3: Physical properties of ABS, PLA, Polypropylene and Nylon

Properties	PLA	ABS	Polypropylene	Nylon
Density (kg / mm^3)	1.25E-06	1.06E-06	8.99E-07	1.12E-06
Young's Modulus (GPa)	4.1	2.24	1.34	2.758
Poisson's Ratio	0.36	0.38	0.392	0.35
Yield Strength (MPa)	26.08	20	30.3	70.4
Ultimate Tensile Strength (MPa)	62.7	29.6	36.5	75.7
Thermal Conductivity (W / (mm C))	1.3E-04	1.6E-04	1.98E-04	2.81E-04
Thermal Expansion Coefficient (/ C)	8.57E-05	8.57E-05	9.05E-05	9.53E-05
Specific Heat (J / (kg C))	120	1500	2731	1670

The yield strength comparison graphs of ABS, polypropylene, nylon and PLA are shown in figure below.

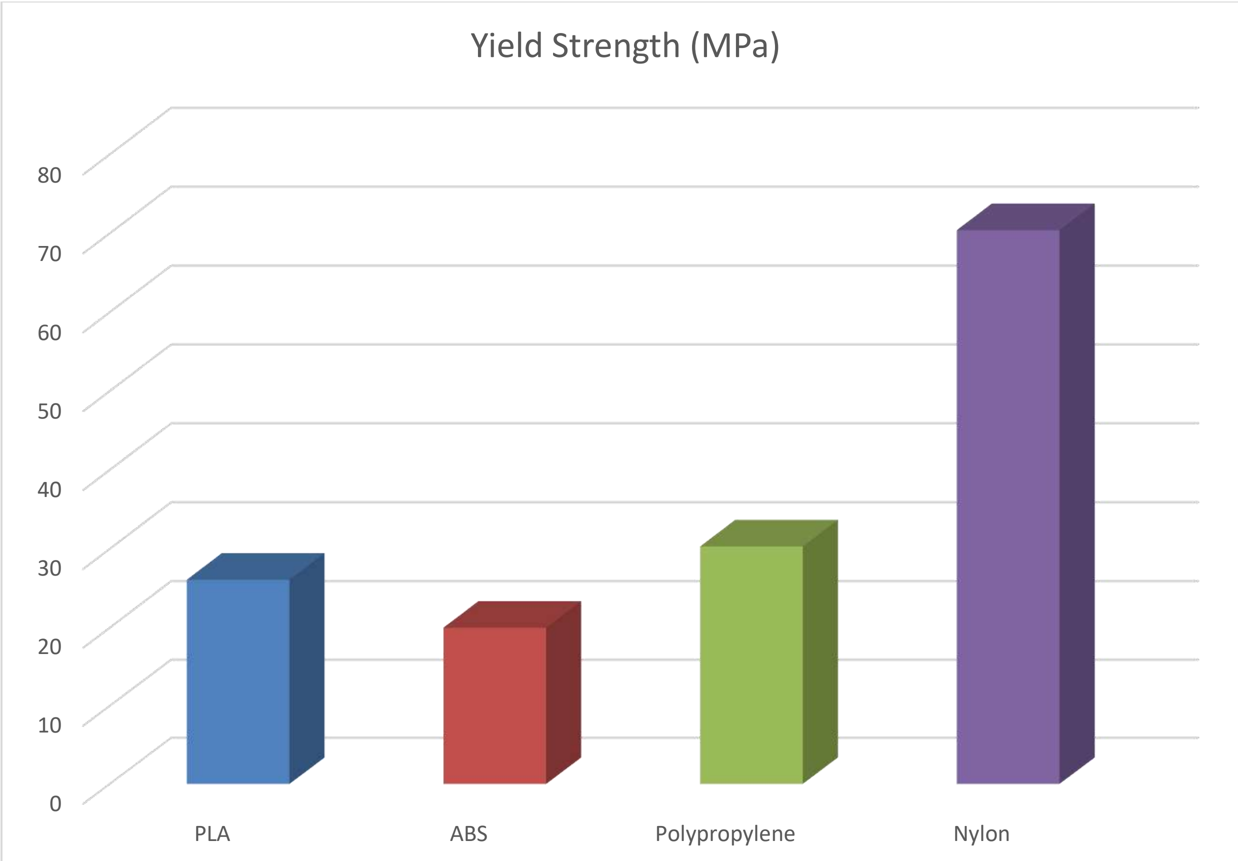

Figure 21 Yield strength comparison of PLA, ABS, polypropylene and nylon

Graphical Comparison of Polymeric Materials

Figure below shows the research results for different polymers shown in one graph.

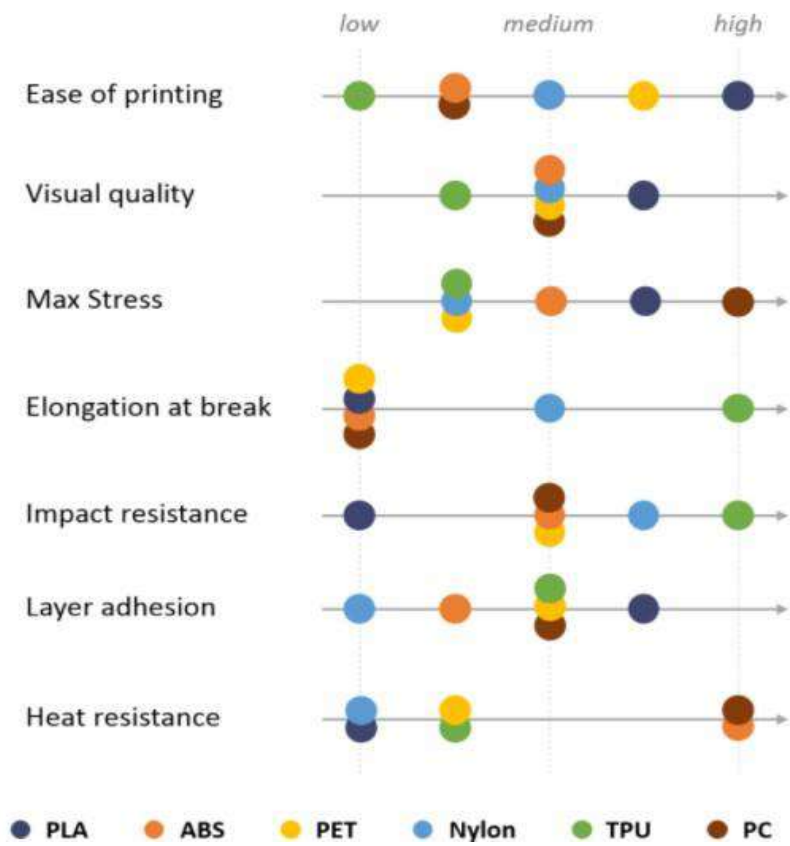

Figure 22 Graphical comparison of polymeric materials (HUBs PROTOLABS, Ins.)

Fused deposition modeling (FDM) in 3D printing requires eco-friendly polymeric materials that offer superior quality and physical as well as mechanical properties. One commonly used material, ABS, possesses good mechanical properties but emits an unpleasant odor during the fabrication process. Conversely, PLA is considered eco-friendly. Interestingly, research indicates that 3D-printed PLA exhibits enhanced mechanical properties compared to injection molded PLA.

Polypropylene is a lightweight and semi-rigid material extensively utilized in storage and packaging applications. However, due to its semi-crystalline structure, 3D printing with polypropylene often results in significant warping upon cooling, presenting a challenge in the printing process.

Nylon is widely favored in industrial 3D printing due to its strength, durability, and resistance to abrasion. When printed with thin layers, it can offer considerable flexibility while maintaining toughness.

Design Analysis

Structural Analysis

Structural analysis involves assessing the impact of applied loads on components and assemblies to ensure they can withstand the forces without failing and compromising their intended functionality. In this process, color codes are used to depict potential failure points, allowing for early identification of flaws during the design phase, prior to manufacturing. This approach accelerates the design process and enhances the overall quality of the product. Finite element analysis (FEA) is particularly valuable for conducting structural analysis, as it serves a specialized purpose in this field.

Finite Element Analysis

Finite element analysis (FEA) is a numerical method applied to model complex structural and thermal solutions. It involves dividing a complex geometry into a limited number of basic geometric elements, known as meshing, with well-defined structural properties. The displacements between neighboring elements are equated at their boundaries, resulting in the formation of a matrix. This matrix is mathematically solved, and the results are visualized through simulations. These simulations display computed stress, deformations, and displacements that occur in the product when subjected to actual stresses and loads.

The simulated results obtained from FEA enable us to optimize the design by making changes and re-performing the analysis. By incorporating structural analysis early in the design phase, the need for costly prototypes and late-stage design modifications is reduced. Moreover, it improves the overall performance, safety, durability, and quality of the model. During bending tests, it was determined that a minimum total force of 50 N (5 N each from the side strips and four on top for band force) caused significant rotational deformations in the DYNAMIC HAND SLPINT. This force value was subsequently used as the loading condition for all FE models of the DYNAMIC HAND SLPINT with alternative trimline designs.

Simulation Results

Within Fusion 360, the finite element analysis (FEA) provides six output parameters: safety factor, stress, displacement, reaction force, strain, and contact force. However, for the purposes of this research, our focus is primarily on the safety factor, stress, and strain.

The FEA was conducted for four different trimlines (elliptical, triangular, and rectangular) and three materials (polypropylene, nylon, and ABS). The obtained results are depicted in the figures below.It is important to note that in the DYNAMIC HAND SLPINT, along with bending, there is a minor torsion occurring at the ankle joint. Although the torsional effect is relatively insignificant compared to bending, it is taken into account. Instead of analyzing normal stress, the von Mises stress output is utilized as it provides a comprehensive representation of the combined effect of tension, compression, shear, and torsion on the structure..

Symbols Colors

In the analysis results, the color codes indicate the expected behavior of the design based on the current analysis criteria.

Red:

Red signifies that the design is likely to experience permanent bending or breakage under the given criteria.

Yellow:

Yellow indicates that the design is marginal, meaning it may be sufficient for its intended purpose, but external factors could potentially cause it to bend or break. In typical design applications, a minimum safety factor of 3.0 is often considered acceptable.

Green:

Green represents a favorable outcome, indicating that the design is not expected to bend or break according to the analysis criteria. It is advisable to validate the analysis criteria and ensure that the safety factor targets align with the standards set by your company, application, and industry.

Summary

This chapter focuses on the product, design, finite element analysis (FEA). The software used for this analysis is Fusion 360, and the modeling steps of the DHS are explained briefly. Detailed dimensions of the DHS are obtained through orthographic projections.

The study involves comparing different materials based on their physical properties for the FEA of DHS. Numerical and graphical comparisons are made to evaluate the performance of materials. The design of the DHS is modified to create three different trimlines, and each of these variations is subjected to a 5N bending force with a fixed base. The entire process is described step by step in this section. The results indicates the following:

1. **Stress Comparison:**

   The comparison shows that the new design exhibits higher stress-bearing capability than the traditional design. In other words, when subjected to the same force or load, the new design can handle higher levels of stress without failure or deformation compared to the traditional design.

2. **Strain Comparison:**

   The trend in strain comparison is exactly the same as the stress comparison. This means that when both designs are subjected to the same force or load, they experience the same trend in strain behavior. The new design shows higher strain capacity, indicating that it can deform or stretch more without experiencing failure compared to the traditional design.

3. **Displacement Comparison:**

   The new design exhibits less displacement under the same loading conditions as the traditional design. Displacement refers to the movement or deformation experienced by the structure due to the applied forces. The lower displacement in the new design suggests that it is more rigid and stable, showing less movement or deformation under the same circumstances compared to the traditional design.

These results indicate that the new design is superior to the traditional one in terms of stress-bearing capability, strain behavior, and displacement under the same loading conditions. It shows better structural performance and has the potential to be more reliable and efficient in practical applications.

PART MANUFACTURING

This section focuses on the fabrication of the dynamic hand splint's components through 3D printing, specifically utilizing the fused deposition modeling technique. It begins with an in-depth introduction to the 3D printer being used, including its specifications, the software employed, printer settings, and the printing procedure. The process involves creating a reduced-size model of the dynamic hand splint using ABS material on the 3D printer.

3D printer

After designing and analyzing the model in Autodesk Fusion360, it is now prepared for 3D printing. However, prior to initiating the printing process, it is essential to calibrate the 3D printer to ensure optimal printing quality. In this case, we utilized a 3D printer and employed the Repetier-Host software package for printing the dynamic hand splint. The specific printing specifications of the 3D printer used are as follows:

i. Print technology: Fused Deposition Modeling
ii. Layer resolution setting: 0.1-0.4mm
iii. Construction dimension: 200*200*170mm
iv. Software package: Repetier-Host
v. Filament diameter: 1.75mm
vi. Nozzle diameter: 0.4mm

Methodology

Preparing and Printing the 3D Model

The 3D printing process involves transforming a digital model into a physical object through a series of precise steps. In this project, the 3D model, crafted using Autodesk Fusion360, has been saved in the .stl format, which is standard for stereo lithography. This digital model serves as the blueprint for the physical object to be created. To facilitate the transition from digital to tangible, the Repetier-Host software is employed. This software translates the 3D model into a series of printer commands that instruct the 3D printer on how to produce the object. The finalized commands are transmitted to the 3D printer using a USB cable, initiating the production process.

Printer Settings and Configuration

To ensure a successful 3D printing process, specific printer settings need to be configured. This configuration involves several key steps:

1. **Opening Repetier-Host Software:** The process commences by launching the Repetier-Host software, the intermediary between the digital model and the physical printer.

2. **Language Selection:** In the software, the language is set to English for ease of use and comprehensibility.

3. **Printer Setting Configuration:** Printer settings are crucial for accurate printing. Configurations like printer dimensions, nozzle specifications, and other parameters are adjusted to align with the requirements of the specific printing project.

4. **Printer Shape Parameters:** Printer shape parameters, including bed size and build dimensions, are specified to guide the printer's movements during production.

Loading the Model and Slicing

Once the printer is appropriately configured, the digital model must be loaded into the software. This is achieved by selecting the "Load" button and ensuring the model is in the .stl file format. After loading the model, various printing preferences are chosen, such as print quality, material type (e.g., ABS), and filament specifics. Once these preferences are defined, the software generates G-code, a set of instructions directing the printer's movements and extrusion during the printing process. The G-code is derived by clicking "Slice with Slic3r," an action that translates the digital model's intricate details into feasible printing actions.

Printing the Model

With the G-code prepared, the actual 3D printing commences. The printer heats up its extruder, melting the chosen filament material (like ABS). The molten filament is then extruded through the nozzle. The printer's movements are controlled by the G-code, allowing the creation of the physical object layer by layer. As the nozzle's temperature reaches the specified setting, the printing process begins in earnest.

Completion and Result

After the printing process is initiated, the printer brings the digital model to life by gradually forming each layer. The outcome is a tangible 3D printed prototype, a faithful representation of the initial digital design. This prototype holds the potential to be a fully functional dynamic hand splint, exemplifying the seamless transition from digital concept to physical reality. The culmination of careful configuration, slicing, and controlled printing culminates in the tangible manifestation of an innovative idea.

In Figure 6.7, the 3D printed prototype stands as a testament to the successful implementation of the designed dynamic hand splint.

Figure 23 3D printed prototype

Summary

This chapter focused on the fabrication process of the dynamic hand splint model using 3D printing technology. The model was successfully created using the fused deposition modeling technique, with ABS chosen as the printing material due to its advantages over ABS and its easy availability. The chapter also provided a comprehensive overview of the 3D printer used for the fabrication, including its specifications and printing settings. Furthermore, the chapter delved into the details of the printer configuration, printing procedure, and the specific steps involved in fabricating the scaled-down model of the dynamic hand splint. This chapter was essential in highlighting the design and fabrication aspects of customized assistive parts, emphasizing the successful creation of the dynamic hand splint model.

RESULTS AND DISCUSSION

Finite Element Analysis Results of Traditional Design and New Design

Once we have collected data then we make 3D design in CAD software of traditional dynamic hand splint, and we have done FEA analysis on it by using three materials which are Nylon, ABS and PP, By comparison we can observe that the nylon shows maximum force bearing capability under same conditions as so the simulation results are shown below.

Table 4 Summary of Simulation Results of Analysis of Tradition Dynamic Hand Splint

Materials	Stress (MPa)	Strain	Displacement (mm)
	Max	Max	Max
Nylon	0.445	0.00061	0.00051
ABS	0.4226	0.00036	0.00033
Polypropylene	0.4267	0.00057	0.00069

From the above Table we can see that nylon is better in terms of stress and strains, and PP is better option is terns of displacement.

Then we have made innovative design without trim lines and again we have done FEA analysis on this new design by using the same three materials so the results are shown below.

Table 5 Summary of Simulation Results of Analysis of New Design of Dynamic Hand Splint

Materials	Stress (MPa)	Strain	Displacement (mm)
	Max	Max	Max
Nylon	0.519	0.009	0.004
ABS	0.498	0.005	0.003
Polypropylene	0.501	0.007	0.005

From the above Table we can see that again nylon is better in terms of stress and strains, and again PP is better option is terns of displacement in new design of hand splint.

Results Comparison of Traditional and New Splint Design Analysis by Bar Graphs

Here, below we are showing the bar graphs to compare which design is more better the tradition or the new on the basis of analysis. By comparison we have observed that new design have high stress bearing capability rather than the traditional one in stress comparison. The strain comparison shows the exact same trend as the strain which indicates the high capability of the new design. In third displacement comparison we can see from the figure 7.1 that new design have less displacement under same circumstances as the traditional one.

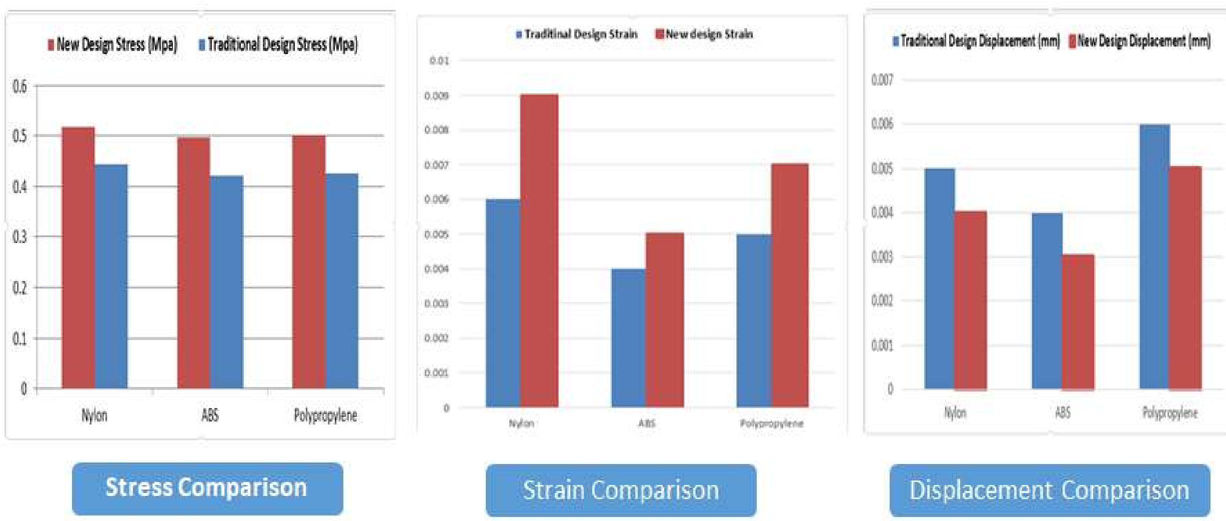

Figure 24 Results Comparison between Traditional and New Design by Bar Graphs

Capabilities of New Design in Comparison to the Traditional Design

1. Higher Stress and Strain Bearing Capabilities:

The new design of the Dynamic Hand Splint, developed using Additive Manufacturing (AM) and Finite Element Analysis (FEA), exhibits higher stress and strain bearing capabilities compared to traditional designs. The FEA process allows for a thorough analysis of the device's structural integrity, identifying areas of potential weakness and optimizing the design to distribute stress and strain more effectively. This results in a splint that can withstand higher forces and pressures, making it more durable and reliable for the user.

2. Customizable Design:

By leveraging AM technology and reverse engineering techniques, the new Dynamic Hand Splint can be customized to fit the unique shape and size of the individual's hand. The 3D scanning of the hand allows for precise measurements, and the CAD software enables adjustments to be made to the splint's design, ensuring a perfect and comfortable fit. Customizability is a significant advantage over traditional manufacturing, as it ensures that the assistive device meets the specific needs of each disabled individual.

3. Aesthetically Better Design:

The AM process allows for intricate and detailed designs that are not easily achievable through traditional manufacturing methods. As a result, the new Dynamic Hand Splint can have an aesthetically pleasing appearance with smooth surfaces and fine details. This aesthetic improvement not only enhances the user's overall experience but also reduces any potential discomfort or skin irritation that could arise from rough edges or poorly finished surfaces.

4. Minimum Waste Generation:

Additive Manufacturing is an inherently more sustainable manufacturing method compared to subtractive techniques (such as machining), where excess material is cut away. With AM, parts are built layer by layer, and only the necessary material is used, minimizing waste generation. Additionally, any unused material from the 3D printing process can often be recycled or reused, further reducing environmental impact.

5. Innovative Features:

The flexibility of AM allows for the incorporation of innovative features and functionalities in the new design of the Dynamic Hand Splint. For example, lattice structures or internal channels can be integrated into the splint to enhance its mechanical properties, reduce weight, and improve ventilation. These innovative features can significantly enhance the device's performance and user experience, setting it apart from traditional, standardized solutions.

6. Adaptable to Injury Level:

The customizability of the new design enables it to be adapted to the specific injury level and requirements of the disabled individual. Whether the user has a mild or severe hand injury or different degrees of paralysis, the Dynamic Hand Splint can be adjusted accordingly to provide optimal support and functionality. This adaptability ensures that the splint is not only effective but also comfortable and supportive for users with varying needs.

7. Reasonable Cost of New Design Part:

While AM technology may have higher initial costs due to the equipment and material expenses, it can be cost-effective in the long run. The ability to customize and produce parts on-demand eliminates the need for expensive tooling or molds, reducing production costs for personalized devices. Additionally, the efficiency of AM in reducing waste and optimizing material usage contributes to cost savings over time.

Finite Element Analysis Results of New Design with Trim Lines

We have made innovative design with trim lines and again we have done FEA analysis on this new design with trim line by using the same three materials so the results are shown below.

Table 6 Summary of Simulation Results of Analysis of New Design with Trim Line

Materials	Stress (MPa)	Strain	Displacement (mm)
	Max	Max	Max
Nylon	0.498	0.008	0.003
ABS	0.465	0.004	0.002
Polypropylene	0.472	0.006	0.004

From the above Table we can see that again nylon is better in terms of stress and strains, and again PP is better option is terns of displacement in new design with trim line of hand splint.

Results Comparison of New Design and New Design with Trim Line Analysis by Bar Graphs

Here, below we are showing the bar graphs to compare which design is more better the new design or the new design with trim line on the basis of analysis.

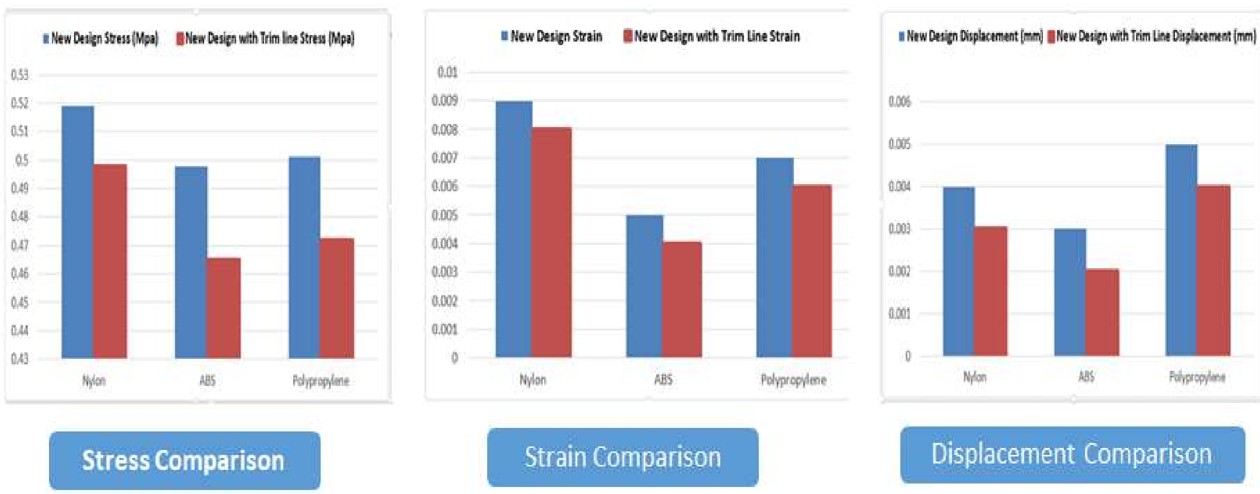

Figure 25 Comparison between New Design and New Design with Trim Line by Bar Graphs

Stress, Strain in trim line design changes because in this design we have less material so it can bear less stress as compare to other design but it will full fill our requirements of stresses and strains.

Capabilities of New Design with Trim Line in Comparison to the New Design

1. **Trim Lines are Material Boundaries**: Trim lines are the boundaries or outlines used to define the shape and remove excess material from the sheets during the manufacturing process. In the context of the Dynamic Hand Splint, trim lines are used to shape and

customize the splint according to the scanned 3D model of the individual's hand. They help in achieving a precise fit and ensuring that the splint is tailored to the unique contours of the patient's hand.

2. **Different Shapes/Designs of Trim Lines**: Trim lines can come in various shapes and designs, such as triangular, rectangular, elliptical, and more. The choice of trim line shape depends on the specific requirements of the assistive device and the patient's needs. Each shape offers different benefits in terms of support, comfort, and aesthetics.

3. **Cost-Effectiveness of Trim Line Design**: Trim line designs are generally more cost-effective compared to creating an entirely new design from scratch. This is because trim lines utilize less material and reduce waste during the manufacturing process. The ability to optimize material usage contributes to cost savings, especially when 3D printing, as the amount of material used directly affects the overall production cost.

4. **Low Weight for Easy Wear ability**: Trim line designs result in a lighter-weight splint compared to bulkier, traditional manufacturing methods. The use of 3D printing with trim lines allows for an optimized structure, reducing unnecessary material, and making the splint easier for patients to wear comfortably. A lightweight splint minimizes the strain on the user's hand, improving overall comfort and usability.

5. **Improved Airflow and Breathability**: The presence of trim lines in the splint design creates space between the layers of the 3D-printed material. This space allows for better airflow and ventilation, reducing the chances of moisture buildup and enhancing breathability. Improved air circulation helps prevent skin irritation and discomfort that may occur with prolonged use of the splint

Summary

This chapter was about the finite element analysis results of traditional, new, and new design with trim lines of dynamic and splint. So, we have used three different materials and we have done FEA analysis for all designs. Then we have made bar graphs for comparison between two designs. Finally we have discussed that which design is having more capabilities in comparison of other designs of dynamic hand splint.

SUSTAINABILITY IN PRODUCT DEVELOPMENT

This chapter delves into the notion of sustainability within a project, emphasizing the need to find a harmonious equilibrium among the environment, society, and economy. It assumes that resources should be used judiciously and efficiently, taking into account long-term priorities and consequences. The chapter explores various strategies for attaining sustainability in both products and processes. Furthermore, it identifies the three fundamental pillars of sustainability and outlines the principles of sustainable product development. The chapter also introduces the concept of Sustainability of Additive Manufacturing (SAM) and discusses how our project incorporates sustainability through the utilization of additive manufacturing technology.

Sustainability

In essence, sustainability involves achieving a harmonious balance between the environment, society, and the economy. It entails integrating environmental well-being, social equity, and economic vitality to foster resilient, healthy, and diverse products, services, and communities that can be sustained over the long term. To address the complexities of sustainability, a systematic approach is required to understand the interconnectedness of various issues. By embracing sustainability, we strive to support the ecological, social, and economic vitality and well-being of our planet and its inhabitants.

Sustainability entails implementing effective and efficient solutions that contribute to the betterment of society, the environment, and industries. This involves maximizing resource utilization, reducing the presence of toxins and waste in the environment, and promoting strategies such as

- Emissions reduction
- Efficient resource allocation
- Reuse
- Recycling
- Diversity.

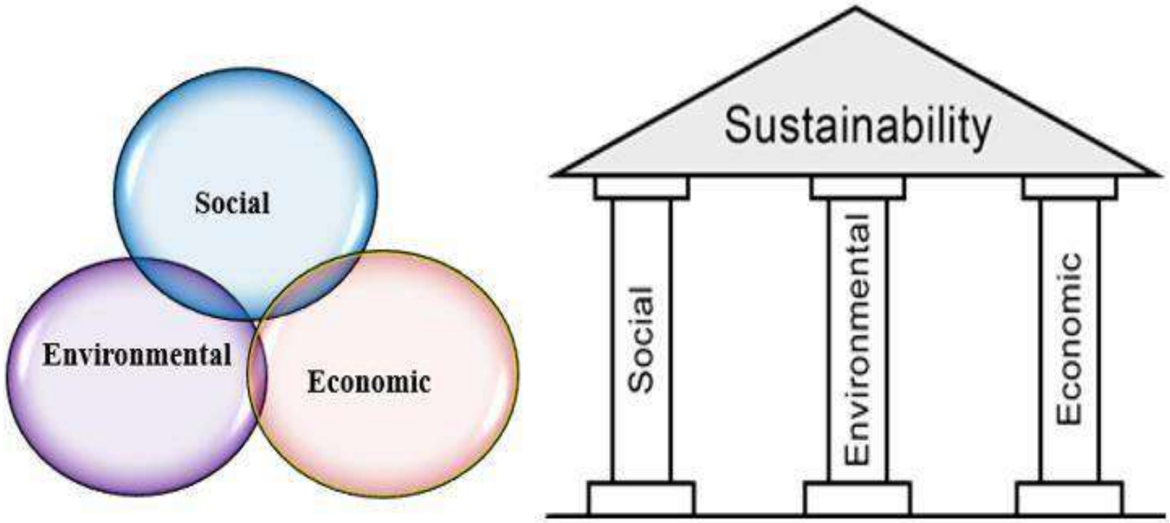

Figure 26 The three pillars of sustainability (seekpng.com)

Sustainable Product Development

Sustainable product development encompasses not only the actual manufacturing of products but also extends to product design. It involves employing a framework for strategic sustainable development, recognizing the increasing demand for products and the environmental consequences of conventional manufacturing processes. Incorporating sustainability into the early stages of product development becomes a competitive advantage for industries. The environmental impacts of product development are most significant during the initial design stages. Therefore, it is crucial to integrate sustainability considerations into the product modeling phase. Environmental impact primarily revolves around emissions and resource management. It is essential to introduce environmental requirements at various stages of a product's life cycle, spanning from design to manufacturing and disposal. To minimize harm to the environment, careful decisions should be made regarding manufacturing tools, techniques, and material selection. Wise choices in these aspects contribute to reducing the negative environmental impacts associated with product development.

Sustainable product development has the following main goals:

- Waste reduction
- Minimizing environmental impact
- Reducing the need for energy
- Efficient resource utilization

- Emissions reduction

Sustainability Development Goals (SDGs)

Our Project is targeting the following SDGs:

3. Good Health and Well-Being

9. Industry, Innovation and Infrastructure

12. Production and Consumption Responsible

Now, let’s explain how these SDGs are related to our project.

SDG number 3 is related to the project as we are working on dynamic hand splint and this is the part of health care industry so after the improvement in this part the health and well-being of patients will increase.

SDG number 9 is related to the project as our full project is based on innovation as we have introduced the innovative thera-bands concept and we have introduced aesthetically innovative design of hand splint which will help in best recovery of patients.

SDG number 12 is related to the project as we are using 3D printing manufacturing method to manufacture our part so this manufacture method produces less waste, and to get more knowledge of this SDG we can see section 8.4, below.

Sustainability of additive manufacturing

Over the past few decades, additive manufacturing (AM) has made significant strides in its development. It has emerged as a technology with remarkable potential for minimizing energy consumption, reducing waste, and employing resource-efficient production techniques. These attributes contribute to lower material requirements within the supply chain and facilitate environmentally friendly manufacturing processes.

Within the realm of sustainability, the concept of Sustainability of Additive Manufacturing (SAM) specifically emphasizes the energy and environmental aspects while promoting efficient resource utilization. In Figure 7.2, a visual representation showcases how SAM aligns with the different pillars of sustainability, illustrating its contribution to ecological, social, and economic considerations.

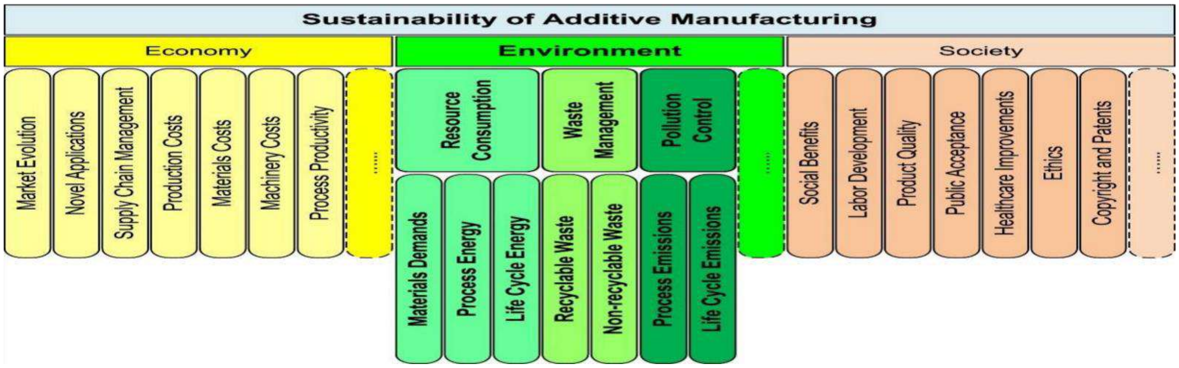

Figure 27 Sustainability of AM (Tau Peng et al ,2018)

Sustainability in the design of customized assistive part is incorporated by efficient and wise selection of material, process, parameters, and by promoting:

- Efficient resource utilization
- Eco-friendly manufacturing
- Reduction of emissions
- Waste reduction
- Sustainable manufacturing

Summary

The main focus of this chapter revolved around sustainability and sustainable product development. The objective of sustainability is to implement efficient and effective solutions that contribute to the improvement of society, the environment, and industries by optimizing resource utilization and reducing waste. To meet this goal, it is essential to integrate environmental requirements into the design and development of new products, making sustainable product development a crucial aspect. Moreover, the chapter delved into the topic of the sustainability of additive manufacturing (SAM) and its significance. SAM is an approach that emphasizes the importance of energy efficiency, environmental considerations, and resource optimization. It provides a framework for incorporating sustainability principles into additive manufacturing processes. Furthermore, the chapter provides an overview of how sustainability is specifically incorporated into the project at hand. It highlights the strategies, methodologies, and practices employed to ensure that the project aligns with sustainable principles and objectives. Hence, we are targeting 3 SDGs in our project which are already explained above.

CONCLUSION AND FUTURE PROSPECTS

This section of the report provides a comprehensive overview of the significant discoveries made during the research project. Furthermore, it offers recommendations for potential future research endeavors that can be undertaken within the scope of this particular field of study.

In the project, we have introduced the innovative concept of thera-bands instead of springs in dynamic hand splint, and we have introduced the aesthetic innovative part design. By FEA analysis we have done the stress, strain and displacement analysis of three different materials. We have used reverse engineering concept to get the customized design of the splints. Finally by 3D printing we have manufactured the part. The field of additive manufacturing (AM) continues to advance rapidly, gradually replacing conventional manufacturing methods. AM enables the production of intricate and highly customized parts with remarkable accuracy. However, further research is still needed to explore various materials and methods in the realm of AM.

This particular study focuses on the utilization of AM technology for designing and manufacturing personalized assistive parts for individuals with disabilities. The part design was accomplished using Autodesk Fusion360 software, followed by structural analysis conducted within the same software for three different materials, namely polypropylene, nylon and acrylonitrile butadiene styrene (ABS). Ultimately, a prototype of the part was printed using ABS material through the fused deposition modeling (FDM) technique.

Key findings from this research project include:

1. Thera-bands concept in splint design is better than spring’s concept in splint design: The Thera-bands concept in splint design involves using elastic bands to provide controlled and adjustable resistance to the movement of joints. This approach allows for a more customized and comfortable fit, as the tension in the bands can be easily adjusted to match the patient's specific needs. The elasticity of the bands also mimics the natural properties of muscles, promoting better proprioception and muscle reeducation during the rehabilitation process. On the other hand, the spring concept in splint design relies on mechanical springs to provide resistance. While springs can offer consistent resistance, they may not offer the same level of adjustability and comfort as Thera-bands. Additionally, springs might exert more pressure on certain areas, leading to discomfort and potential skin irritation. Therefore, the Thera-bands concept is considered superior in terms of versatility, patient comfort, and rehabilitation effectiveness.

2. New Design splint is better than traditional design Splint: The statement suggests that a new design splint outperforms traditional design splints. New designs in splint may incorporate advanced materials, innovative construction techniques, or enhanced biomechanical principles. These improvements can lead to better support, improved patient compliance, and more effective immobilization or movement facilitation, depending on the intended purpose of the splint. Traditional design splints, while effective, might lack the latest advancements and improvements that come with modern design approaches. Therefore, a new design splint has the potential to offer enhanced performance, comfort, and overall treatment outcomes compared to its traditional counterparts.
3. New Design with trim line splint is better than modified/new design splint: This statement compares two types of splints: one with a trim line design and another with a modified or entirely new design. A trim line splint typically has a well-defined edge that closely follows the contour of the body part it is meant to support. This allows for better fit, stability, and reduced bulkiness. On the other hand, modified or new design splints might have unconventional shapes or unique features to address specific patient needs or clinical requirements. While both types can be effective, a new design with a trim line splint combines the benefits of customization, improved fit, and functionality. The trim line design minimizes unnecessary bulk while still providing adequate support, making it more comfortable for the patient and potentially leading to better treatment outcomes.
4. By reverse engineering, we can make customized designs of splints in less time: Reverse engineering refers to the process of analyzing an existing product to understand its design, structure, and functionality in order to recreate or modify it. In the context of splint design, reverse engineering allows healthcare professionals to scan or analyze a patient's anatomy or an existing splint to create a customized design that precisely fits the individual's unique needs. Traditional methods of splint design might involve manual measurements and trial-and-error adjustments, which can be time-consuming and less accurate. With reverse engineering techniques, the digitized data can be directly used to create a personalized splint design using computer-aided design (CAD) software and additive manufacturing technologies. This streamlined process not only saves time but also improves the accuracy and efficiency of the splint manufacturing process.
5. Additive manufacturing technology facilitates the production of highly customized and specialized products effectively: Additive manufacturing, commonly known as 3D printing, is

a transformative technology that allows for the creation of three-dimensional objects layer by layer from digital designs. This unique manufacturing approach enables the production of highly customized and specialized products, including splints, with unparalleled design freedom. Unlike traditional manufacturing methods, which often involve costly and time-consuming tooling processes for each variation, additive manufacturing requires minimal setup changes between different designs. This makes it ideal for creating personalized splints tailored to individual patients' anatomical needs. The flexibility of additive manufacturing also allows for the incorporation of complex geometries and internal structures, which can enhance the splint's performance, comfort, and functionality.

6. Fused deposition modeling technique can be employed to manufacture assistive devices for disabled individuals. However, careful consideration must be given to material selection, mechanical properties, and printing parameters within the additive manufacturing process: Fused deposition modeling (FDM) is a popular 3D printing technique commonly used in the additive manufacturing of splints and assistive devices. FDM works by extruding thermoplastic material through a heated nozzle to create layers that gradually build up the final object. This method offers several advantages, such as ease of use, low cost, and accessibility. However, when manufacturing assistive devices for disabled individuals, careful consideration of material selection is vital. The chosen material must exhibit appropriate mechanical properties, such as strength, flexibility, and biocompatibility, to ensure the safety and comfort of the patient. Moreover, optimizing printing parameters, such as layer thickness and printing speed, is essential to achieve the desired quality and precision of the final product. By addressing these considerations, FDM can be a valuable tool for creating personalized and effective assistive devices.
7. Additive manufacturing is particularly well-suited for mass customization, while injection molding is more appropriate for mass production scenarios: Additive manufacturing and injection molding are two distinct manufacturing processes, each with its own strengths and limitations. Additive manufacturing excels in producing customized products on-demand, making it highly suitable for mass customization. In the context of splints, patients often require personalized devices that precisely fit their unique anatomy and address specific medical conditions. Additive manufacturing can easily accommodate such individualized requirements without the need for expensive tooling or extensive setup changes between batches. On the other hand, injection molding is more appropriate for mass production

scenarios where large quantities of identical splints need to be manufactured efficiently and cost-effectively. While injection molding might not offer the same level of customization as additive manufacturing, it can produce splints in bulk, significantly reducing unit costs and production time.

8. All materials that are polypropylene, nylon, and ABS demonstrate competitiveness for 3D printing applications. However, ABS is preferred due to its eco-friendly manufacturing process and biodegradability: Polypropylene, nylon, and ABS are three commonly used materials in 3D printing applications, including the manufacturing of splints. Each material offers distinct advantages and characteristics that suit various purposes. Polypropylene and nylon are known for their excellent durability, flexibility, and resistance to chemicals, making them suitable for producing functional splints that require high strength and longevity. On the other hand, ABS combines good strength with a more eco-friendly manufacturing process compared to traditional plastics, as it can be derived from renewable resources or recycled materials. Moreover, ABS is biodegradable, which is an important consideration for reducing the environmental impact of discarded splints. While all three materials have their merits, the eco-friendly nature and biodegradability of ABS make it a preferred choice in certain contexts.
9. Additive manufacturing exhibits greater sustainability compared to injection molding in terms of environmental friendliness and efficient resource utilization: Additive manufacturing is often considered more sustainable than traditional manufacturing methods like injection molding due to several factors. Firstly, additive manufacturing is an "on-demand" process, meaning it produces items as needed, reducing overproduction and minimizing waste. In contrast, injection molding typically involves producing large quantities of items, which can lead to excess inventory and material wastage. Secondly, additive manufacturing generates significantly less material waste because it adds material only where it is needed, whereas injection molding often generates excess material as part of the sprue and runner system.
10. Printer settings and printing parameters play a critical role as they directly impact the quality of printing and surface finish of the manufactured parts.

Future Recommendations

1. Use of Artificial Intelligence to detect the patient's injury level in radial nerve palsy. Artificial Intelligence (AI) can play a significant role in detecting the injury level in radial nerve palsy. AI algorithms can be developed and trained using patient data, medical imaging, and clinical

assessments to accurately assess the severity of the condition. By analyzing various factors such as muscle strength, range of motion, and sensory perception, AI models can provide insights into the extent of the nerve damage. The use of AI in this context offers several benefits. It can provide a more objective and consistent evaluation compared to manual assessments, which may vary based on the expertise of the healthcare professional. AI algorithms can process large amounts of data quickly, allowing for faster and more efficient diagnosis. This can aid in early detection of radial nerve palsy and facilitate timely intervention and treatment planning. Additionally, AI can also assist in tracking the progress of the condition over time, providing valuable insights for ongoing patient management.

2. Use of "Smart Materials" while manufacturing splints for dynamic hand splint. When manufacturing splints for dynamic hand splint applications, incorporating "Smart Materials" can enhance their functionality and adaptability. Smart materials are reactive materials that can change their properties in response to various stimuli, such as electric and magnetic fields, stress, moisture, and temperature.

REFERENCES:

1. Chapman LS, Redmond AC, Landorf KB, Rome K, Keenan AM, Waxman R, et al. Foot orthoses for people with rheumatoid arthritis: a survey of prescription habits among podiatrists. J Foot Ankle Res. 2019;12:7.
2. Gerrard JM, Bonanno DR, Whittaker GA, Landorf KB. Effect of different orthotic materials on plantar pressures: a systematic review. Journal of foot and ankle research. 2020 Dec;13(1):1-1.
3. Tao Peng, Karel Kellens, Renzhong Tang, Chao Chen, Gang Chen, Sustainability of additive manufacturing: An overview on its energy demand and environmental impact, Additive Manufacturing https://www.sciencedirect.com/science/article/abs/pii/S2214860417302646
4. AOPA What is an orthotics? Available:https://www.aopa.org.au/careers/what-are-orthoses-and-prostheses (accessed 4.6.22)
5. Webster JB, Murphy DP, editors. Atlas of orthoses and assistive devices. Amsterdam, The Netherlands:: Elsevier; 2019.
6. Jarvis HL, Nester CJ, Bowden PD, Jones RK. Challenging the foundations of the clinical model of foot function: further evidence that the root model assessments fail to appropriately classify foot function. Journal of foot and ankle research. 2017 Dec;10(1):1-1.
7. Chui KC, Jorge M, Yen SC, Lusardi MM. Orthotics and Prosthetics in Rehabilitation E-Book. Elsevier Health Sciences; 2019 Jul 6.
8. Mangai S, Ranganathan R, Pugalendhi A, Gokul Raj N, Deepan Raju S, Dharani T, Durga R. Design And Development Of Ankle Foot Orthosis Using Additive Manufacturing Technique. 2020
9. Leslie K. King, *Introduction to Orthotics and Prosthetics*, Introduction to Orthotics and Prosthetics | Clinical Gate
10. Menz HB, Allan JJ, Bonanno DR, Landorf KB, Murley GS. Custom-made foot orthoses: an analysis of prescription characteristics from an Australian commercial orthotic laboratory. Journal of foot and ankle research. 2017 Dec;10(1):1-9.
11. Nester CJ, Jarvis HL, Jones RK, Bowden PD, Liu A. Movement of the human foot in 100 pain-free individuals aged 18–45: implications for understanding normal foot function. Journal of foot and ankle research. 2014 Dec;7(1):1-0.
12. Condie & Meadows Report of a consensus conference on the lower limb orthotic management of cerebral palsyInternational Society for Prosthetics and Orthotics(1995) ISBN 9788789809021
13. Karakas & Hoy (2002)
14. Owen E. The Effects of Tuning an Ankle-Foot Orthosis Footwear Combination on Kinematics and Kinetics of the Knee Joint of an Adult with Hemiplegia Prosthetics and Orthotics (2014) 34(3): 270-6
15. 1. Elizabeth Wojciechowski, A.Y.C., Daniel Balassone, Jacqueline Ford, Tegan L. Cheng, David Little, Manoj P. Menezes, Sean Hogan & Joshua Burns, *Feasibility of designing, manufacturing and delivering 3D printed ankle-foot orthoses: a systematic review*. Journal of Foot and Ankle Research, 2019: p. 11.
16. 2. Gautam, G.Y., L.J. M, and G. Vijay,, *DESIGN AND ANALYSIS OF THERMOPLASTIC POLYPROPYLENE ANKLE FOOT ORTHOSIS.* Journal of Manufacturing Engineering, , 2021. . p. 16(3): p. 087-091.
17. 3. Neelesh Kumar Dubey, S.G., *Comparative Analysis of Different Composites for Ankle Foot Orthosis: A Review.* Advances in Engineering Materials, 2021.
18. 4. Bregman, D.J., et al.,, *Polypropylene ankle foot orthoses to overcome drop-foot gait in central neurological patients: a mechanical and functional evaluation.* . Prosthet Orthot Int, , 2010. : p. 34(3): p. 293-304.

19. 5. Abdalsadah, F.H., et al.,, *Design and manufacture of a custom ankle–foot orthoses using traditional manufacturing and fused deposition modeling.* Progress in Additive Manufacturing, , 2021. : p. 6(3): p. 555-570.
20. 6. Pandey, R.a.R.S., *Experimental Analysis of Various Materials on Custom-Fit Ankle Foot Orthosis.* . Journal of Physics: Conference Series,, 2021. : p. 1950(1): p. 012028.
21. 7. Banga, H.K., et al.,, *Fabrication and stress analysis of ankle foot orthosis with additive manufacturing.* . Rapid Prototyping Journal, , 2018. : p. 24(2): p. 301-312.
22. 8. Deckers, J.P., et al.,, *Development and clinical evaluation of laser-sintered ankle foot orthoses.* . Plast Rubber Compos , 2018.: p. 47.
23. 9. Faustini, M.C., et al.,, *Manufacture of passive dynamic ankle-foot orthoses using selective laser sintering.* IEEE Trans Biomed Eng, , 2008. : p. 55.
24. 10. Telfer, S.a.J.W., *The use of 3D surface scanning for the measurement and assessment of the human foot.* . J Foot Ankle Res, 2010: p. 3.
25. 11. Cha, Y.H., et al., , *Ankle-Foot Orthosis Made by 3D Printing Technique and Automated Design Software.* . Applied Bionics and Biomechanics, 2017., 2017:: p. p. 9610468.
26. 12. .
27. 13. Langer, R. *NAE GRAND CHALLENGES FOR ENGINEERING*. 2019; Available from: http://www.engineeringchallenges.org/.