International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14, Issue 09, RTMSE-2026

Mechanical Design and Analysis of 3-D Printed Prosthetic Hand for Transradial Amputees

Er. Harpreet Pal Singh
Dept. of Mechanical Engineering
Punjabi University, Patiala
harpreet1890@gmail.com

Dr. Parlad Kumar
Dept. of Mechanical Engineering
Punjabi University, Patiala
pkgarg4050@gmail.com

Abstract - Current prosthetic hand three-dimensional design for transradial amputees was developed using creo platform. Prosthetic limbs developed in older times were generally heavy, comprised of limited functionality and manual operations due to traditional designing and manufacturing techniques besides disadvantage of utilizing conventional materials. Consequentially older prosthetic hands were not able to address adequate assistance to amputees in carrying out daily living activities due to lesser dexterity and limited biomechanical traits. Nowadays, using computer aided design and manufacturing techniques makes it easier to design and manufacture complex mechanical assemblies with higher accuracy and precision. In current research work, computer aided engineering-based analysis of three-dimensional hand model was carried out to evaluate realistic behavior of prosthetic hand under the loading conditions. Finger joints were assessed to study the endurability and strength of hand structure design by applying loading and boundary conditions at critical regions using finite element analysis method. Also, in the present work, a significantly used additive manufacturing three-dimensional printing technique was applied to manufacture prosthetic hand parts for rapid prototyping and to fulfill instant need of newly designed parts for experimentation purpose according to specific personal requirements of an individual.

Keywords - Computer aided design & manufacturing; Finite element analysis; 3-D Priniting; Optimization ; Functionality

I. INTRODUCTION

The technology to develop prosthetic devices for differently-abled people have been advanced immensely now a days but in earlier times it was more important to provide good aesthetic look to prosthetic limbs contrary to biomechanical functionality due to technological impediments. Design and fabrication of prosthetic limbs in 19^{th} century were difficult to accomplish due to traditional designing and manufacturing techniques along with the limitation of using conventional materials consequentially prosthetic hands were not able to attain the desired functionality and dexterity [1].

But in present times it is easier and time saving to develop complex anthropomorphic prosthetic hand designs with higher dexterity using computer aided design, manufacturing and analysis (CAD/CAM/CAE) tools.

II. FUNDAMENTAL ASPECTS OF PROSTHETIC HAND DESIGN

Design and fabrication are crucial aspects of development of complex structural assembly comprising motion mechanism components in development of prosthetic devices. Primary function of prosthetic hand is to mimic the important hand movements to carry out different activities a healthy person does for living. The motion mechanism assembly of prosthetic hand was developed to transmit forces from motor actuator to fingers and palm movement through kinematic links to mimic desired hand movements including gripping actions. Current prosthetic hand 3D model for trans-radial amputees was developed using advanced Creo platform with an ability to detailed design and analysis of complex assemblies. CAE based analysis of 3D hand model was carried out to evaluate realistic behavior of prosthetic hand under the loading conditions using finite element method. In current hand design the finger joints are assessed to study the endurability and strength of hand structure design by applying loading and boundary conditions using computer simulation. Computer software's simulation allows to develop complex dynamic assembly designs without compromising the desired levels of dexterity, functional capability and mechanical strength. CAE tools are extensively used for analysis of stress, deformation and motion study of functional mechanism. A small and precise manipulations can be significantly evaluated from motion input to output at end effector which directly reduces overall experimentation and development cost of prosthetic hand prototype. The foremost features of prosthetic hand are its functionality, gripping force, weight and control feature strategy. But as the time passes, specifically during the 21^{th} century, with the development of state of arm prosthetic devices that works on cable operated or spring-based mechanisms with higher dexterity came into existence which helped the users to perform small and precise manipulations to perform various tasks like gripping the objects and maintaining postures more effectively [2].

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14, Issue 09, RTMSE-2026

Fig.1. 3-D Proposed design of prosthetic hand

3D printing technology is generally more effective for research and development activities but not suitable for mass production of prosthetic devices. The prosthetic hand market is flooded with diverse types of hand prosthesis with distinct working methods, designs and control techniques. Other factors like actuation principal and manufacturing materials also imparts a striking impact on overall performance of prosthesis functions. These are mainly classified into two types such as active or passive prosthesis. Active prosthesis is more commonly used nowadays due to its extended features of dexterity and functionality using motor actuators with portable power source. Bionic hand, Electric powered prosthesis, myoelectric arms or hybrid type of prosthesis falls under active prosthesis [3].

TABLE I.

Comparison of structural and working parameters- Real hand vs Prosthetic hand

Parameters	**Real hand**	**Prosthetic hand**
Structure	27 Bones, Intrinsic and extrinsic Muscle, Joints, tendons [4]	Structural frame with finger subassemblies and joints made of metals and non-metals
Material	Bones, Ligaments, Muscles, Skin, blood vessels, tendons and nerves	ABS, steel, copper, PVC, aluminum and other artificial materials
Actuation mechanism	Contraction of Intrinsic and extrinsic muscles and tendons thereby turning joints [5]	Cable based or linkage-based mechanism, integrated cable-linkage based mechanism
Power source	Energy by metabolism	Electric charge by battery or external source
Degree of Freedom	Approx. 22 DOF [6]	Approx. 1-16 DOF
Motion, Posture and Gripping Capacity	Power grasp, precision, pinch, spherical, lateral, point, V, hand shake, shaka sign and other complex gestures like hand waving etc. [7]	Majorly accomplish power grasps but lack of precision and posture movements in majority of hands
Stability	Highly stable, Self-accommodating power and movement integrity	Stability affected generally during difficult tasks and postures
Controls	Through brain signals and nervous system interaction [8]	Manual harness transmission, EMG Based, Neural or Brain, Sensors and switch based, hybrid controls
Strength and loading capacity	High gripping force approx. 300-550 Newtons and higher weight carrying capacity varying case to case [4]	Grip force is usually lower and also the weight carrying capacity based on motor power, mechanism links and joints and type of material used

III. DESIGN OF PROSTHETIC HAND

as shown in figure 1, in the current prosthetic hand design the key movements of fingers needed to attain desired range of motion are grasping and ungrasping of an object. The most commonly used working mechanism of prosthetic finger is cable-based fingers extension and flexion drive mechanism. In this mechanism, the hand fingers are designed to remain in extended position normally and start to flex inwards towards the palm upon pulling the cables incrementally. The extent of flexion depends upon the extent up to which finger sub parts turn about each other at Metacarpophalangeal (MCP), Proximal Interphalangeal (PIP), Distal Interphalangeal joints (DIP) fulcrum axis with standard sizes [9].

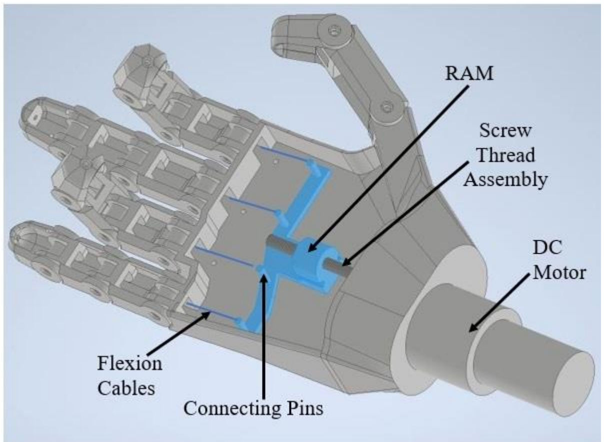

Fig.2. Gripping mechanism through RAM movement

Flexion movement begins from higher to lowest angle about the fulcrum axis of the distinct joint between the two finger subparts that makes enables one or more finger to hold the grip on an object. However, cable-based finger activating mechanism also withhold the disadvantage of catering small grip force upon pulling the extension and flexion cable. Gripping mechanism and principal of return mechanism. But in current design this disadvantage is overcome by using screw thread mechanism which does not yield backlash and provide firm passive grip even upon switching off the power supply. Transradial amputation is very common type among amputees where the hand is severed from the forearm section in the upper extremity.

IV. GRIPPING MECHANISM AND PRINCIPAL OF RETURN MECHANISM

Human hand functional traits are quite complex as it mimics complex communicatin based gestures, dynamic functional manipulations to accomplish multiple tasks [10]. The complexity raises when a hand is able to accomplish single task such as holding a key while opening a car door or holding any single or multiple objects while opening a door using separate fingers for doing independent or collabrative

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14, Issue 09, RTMSE-2026

action. The hand movements are classisified into two types such as prehensile, illustrated by gripping and non-prehensile, signified as gestures, point, manupulative actions [11].

The assessment of kinematic aspects of precise assembly components was carried out to validate the output of prosthetic hand at different positions and angles of fingers during gripping. The bending of finger subparts around the joint axis required to be moved at specified angles without concussion. Another crucial design parameter was assessing gripping action by fingers either individually or collectively. Each prosthetic finger possesses distinct number of movements complying with specific degree of freedom with the joint movements during flexion and extension movements during the gripping and releasing of an object. Based on biomechanical traits of a real human hand, the kinematic design of a prosthetic hand was developed to achieve similar kind of structural anatomy. The working of a current prosthetic hand kinematic mechanical assembly of prosthetic constitutes cable and linkage-based mechanism which pull the extension cable in single stroke of RAM linearly but in increments as desired and activated by DC motor power. The transmission of force for gripping action from DC motor shaft was transmitted through RAM pulling the flexion cables as shown in figure 2.

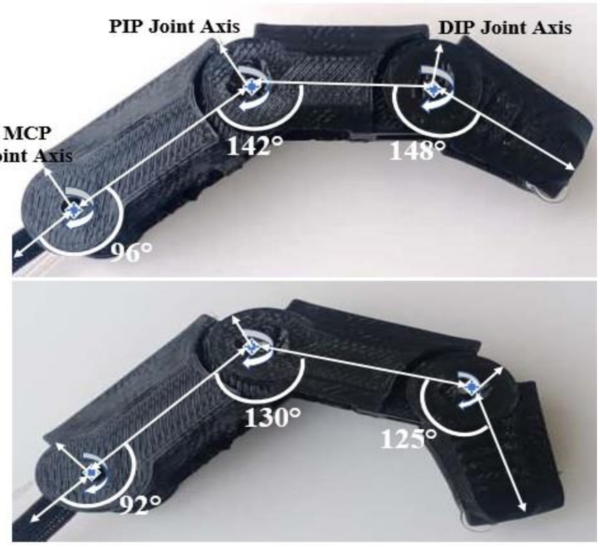

Fig.3. 3-D Printed fingers joint angles

The rigid RAM moves through the grooves formed inside the structural frame constitutes 5 pins which are attached to each digit using a flexion cable at palmer side of fingers as shown in figure 2. As the DC motor rotates in clockwise direction the RAM begins to move forward linearly and the flexion cables are tightened upon pulling but on the dorsal side the extension cables in the form of elastic string begin to extend. During the rotation of motor in reverse direction the extension cables are slackened therefore extension cables tends to return back due to its elastic potential energy that tends to restore the initial position according to Hooks Law. The grasping and ungrasping of hand follows the alternative course of action when the power shifts from flexion cables at palmar side to the extension cables at dorsal side and vice versa.

Grasping speed or bending of fingers inwards depends upon the velocity of pulling the flexion cables through the motor actuator. The key parameters controlling the speed of gripping or finger flexion depends upon a) Motion Mechanism assembly response b) Speed of Motor actuator, in current design the RPM of DC motor c) MCP, PIP and DIP joint angles mainly [12]

V. DESIGN ANALYSIS USING FEM

Using CAE analysis, the optimization of hand design was done to ensure the long term endurability under maximum loading conditions usually at suspected weaker regions. The analytical study is carried out using finite element method in Creo simulation.

The analysis was carried out at two regions during setting up the load and boundary conditions in which first region was ABS material study at the joint and second was deflection of steel pin that connects the finger subparts to each other or with hand palm section as discussed below.

A) Analysis Results of ABS material joint portion

The analysis results are depicted by analyzing the stress, displacement, strain and P-values generated after setting up the loading and boundary conditions. The ABS material is light weight thermoplastic polymer with higher formability characteristics in FDM but material density, elastic modulus, tensile strength are also crucial parameters. In current analytical study of ABS material with isotropic behavior, the young's modulus is taken 3.249E+05 psi, Poisson's ratio 0.38, shear modulus 1.168E+05 psi, density 0.038 pound per cubic inch, yield strength 2.901E+03 psi and tensile strength 4.293+03 psi. As shown in figure no. 3 to 4, the load of 15 newtons which was approximately 1.5 kg was applied on MCP joint cavity without steel pin. In boundary conditions, the hand movements were constrained in all X, Y, Z coordinates [13].

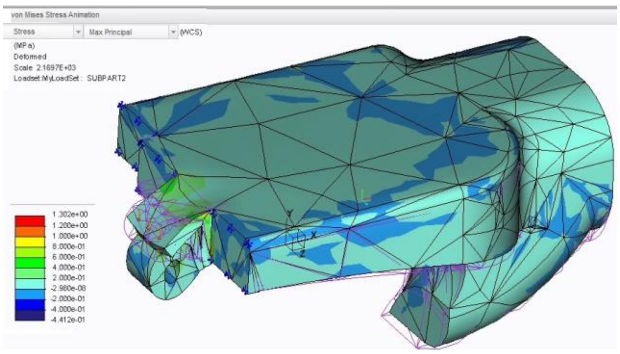
Fig.4. Stress at maximum principal plane

Stress at maximum principal plane is displayed at red yellowish area near MCP joint as shown in figure no.3. The maximum stress by von- mises analysis was observed 3.692 Mpa at highlighted region.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14, Issue 09, RTMSE-2026

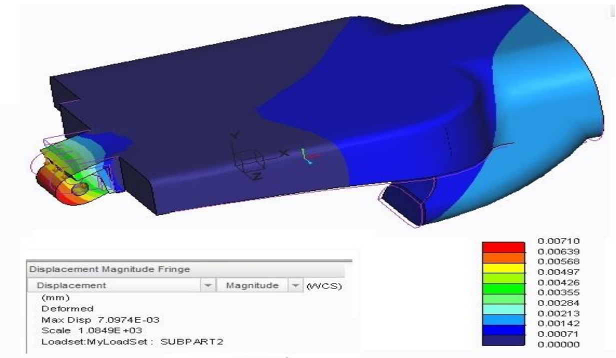

Fig.5. Maximum Displacement at joint

Maximum displacement displayed at the end of MCP joint at extruded region is highlighted in red color as shown in figure 4. At that highlighted region the maximum displacement was observed 0.007 mm along the MCP joint and maximum P-level was achieved 7 which is satisfactory as it does not cause failure by developing cracks under cyclic conditions. during the maximum gripping force. This results also indicates the optimal material thickness a joint cross-sectional area. However, in order to minimize the overall material weight without compromising the strength at any region thereby reducing the cost by reducing the material thickness as desired without affecting part strength.

B) Analysis Results of steel pin at finger joint

Each finger joint MCP, PIP and DIP are attached to each other using rotational pin joints with one degree of freedom at each. The material of joint pin was taken a steel and its size was taken Ø5 mm and length 20 mm equal to finger width.

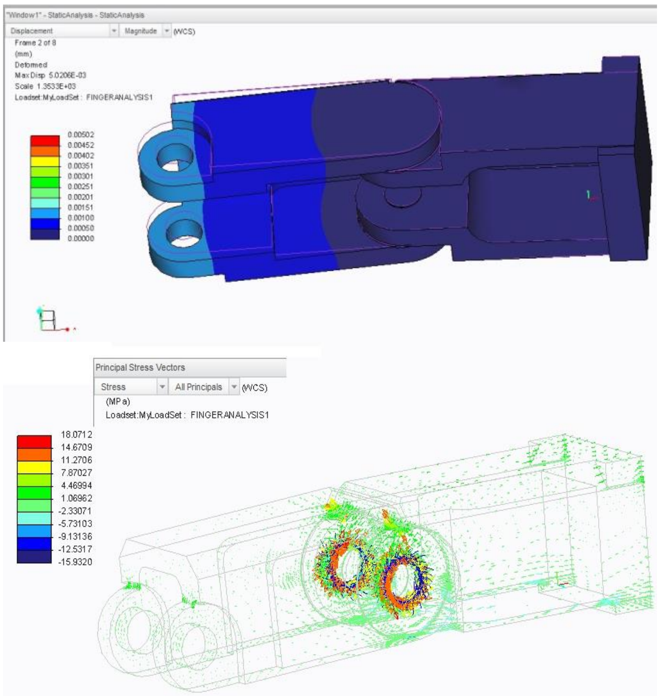

Fig.6. Maximum strees and displacement at finger joint steel pin

The standard steel pin material is used for making a joint connection where the. In current analytical study of ABS material with isotropic behavior, the young's modulus is taken 2.799E+07 psi, Poisson's ratio 0.30, shear modulus 1.247E+07 psi, density 0.289 pound per cubic inch, yield strength 3.626E+04 psi and tensile strength 7.832+04 psi. Stress at maximum principal plane is observed as 18.07 Mpa without any considerable displacement where the load of 12 newton was taken on a single pin.

VI. MANUFACTURING PROCESS OF PROSTHETIC HAND

Among the vast classifications of prosthetic hands, the functionality and affordability are the foremost concerns specifically in developing countries. Significant additive manufacturing techniques such as Fused Deposition Modeling (FDM) or 3D printing is used now a days to rapidly manufacture customized parts as per instant need and specific personal requirements of an individual at affordable cost. The hand prototype model was built up using FDM techniques with Acrylonitrile Butadiene Styrene (ABS) material due to its formability in 3-D printing and significant damping properties under cyclic stress. The FDM process utilizes the manufacturing using layer by layer extrusion of ABS material by attaining semi liquid or near solid state under controlled temperature inputs [13].

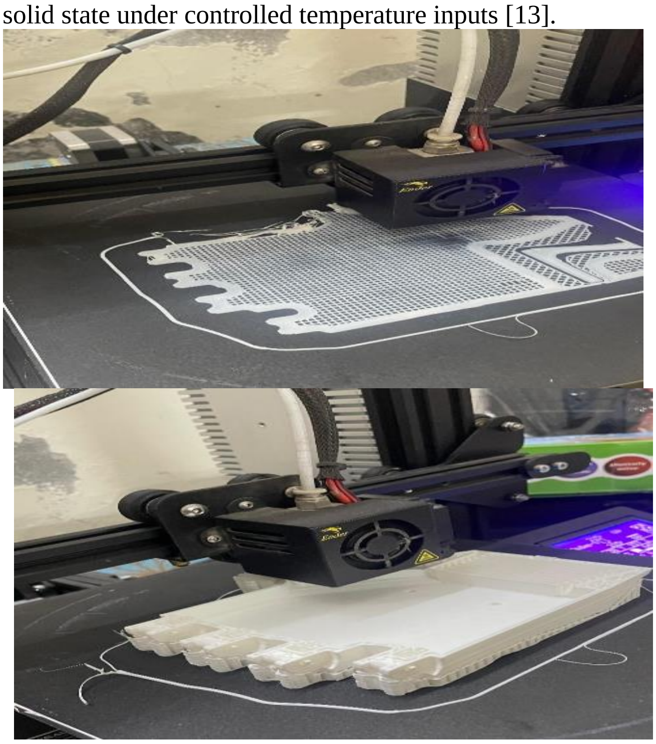

Fig.7. FDM process during prosthetic hand manufacturing

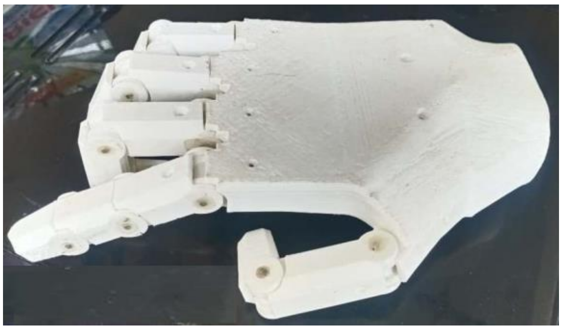

Fig.8. 3D Printed prosthetic hand completely assembled

The prosthetic hand design model was developed using CAD software in part file format which was converted into Stereolithography (STL) file format. The STL file was again processed and converted into SLS format file. The SLS format contains the details of 3-D model which was fragmented into small cross sections with desired parameter ranges of raster width, built up size and pattern under optimal resolution to be followed up on FDM machine. In FDM manufacturing process, the ABS material in the form of filament was pushed through the drive wheels moved by motor power to the heating chamber for layer-by-layer sintering [14-15]. This yields easy and continuous process of forming customized parts with higher precision, enhanced accuracy and speed.

CONSLUSION

The prosthetic hand design posses' multiple joints bearing dynamic loads at difference angles and positions particularly during grasping an object. The artificial hand design mechanism is generally complex to accommodate different positions with or without gripping. To achieve both dexterity and functionality in prosthetic hand, precise assembly component manipulations in a constrained manner usually required. The small backlash or restriction in a motion transmission could lead to entire functional failure of hand manipulations. CAD software made it easy and unerring framework in designing the motion mechanism with dexterous functional movements besides explicit dimensional accuracy. 3-D printing also provides a dimensional accuracy as compared to other most of traditional manufacturing operations. Therefore, using CAD and CAM techniques, the better versions of complex prosthetic hand designs with higher functionality and stability can be developed.

REFERENCES

[1] M. Salazar, P. Portero, M. Zambrano, R. Rosero. Review of Robotic Prostheses Manufactured with 3D Printing: Advances, Challenges, and Future Perspectives. *Applied Sciences*. 2025; 15(3):1350. https://doi.org/10.3390/app15031350

[2] P. Wattanasiri, P. Tangpornprasert and C. Virulsri, "Design of Multi-Grip Patterns Prosthetic Hand With Single Actuator," in *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, vol. 26, no. 6, pp. 1188-1198, June 2018, doi: 10.1109/TNSRE.2018.2829152.

[3] J.T.Belter, and L.S. Jacob . "Mechanical design and performance specifications of anthropomorphic prosthetic hands: A review." *Journal of rehabilitation research and development* 50.5 (2013): 599. S

[4] A. Kargov, C. Pylatiuk, J. Martin, J., Schulz, S., & L. Döderlein. (2004). A comparison of the grip force distribution in natural hands and in prosthetic hands. *Disability and Rehabilitation*, 26(12), 705–711. https://doi.org/10.1080/09638280410001704278

[5] V.H. Moraes, C.D. Vargas, Ramalho BL, et al. Effect of muscle length in a handgrip task on corticomotor excitability of extrinsic and intrinsic hand muscles under resting and submaximal contraction conditions. *Scand J Med Sci Sports*. 2023;33:2524-2533. doi:10.1111/sms.14477

[6] H. Yang, Z. Tao, Yang, J. *et al.* A lightweight prosthetic hand with 19-DOF dexterity and human-level functions. *Nat Commun* 16, 955 (2025). https://doi.org/10.1038/s41467-025-56352-5

[7] L. Sparaci, V. Volterra,. (2017). Hands Shaping Communication: From Gestures to Signs. In: Bertolaso, M., Di Stefano, N. (eds) The Hand. *Studies in Applied Philosophy, Epistemology and Rational Ethics*, vol 38. Springer, Cham. https://doi.org/10.1007/978-3-319-66881-9_3

[8] Gentile C, Gruppioni E. A Perspective on Prosthetic Hands Control: From the Brain to the Hand. Prosthesis. 2023; 5(4):1184-1205.

[9] Arslan L, Aydın M. Three-Dimensional Design of a Robotic Hand with Proximal and Distal Interphalangeal Joints. *Journal of materials and electronic devices*. 2025 Sep 1;1(1):12-20.

[10] T.L. Kivell, N. Baraki, V. Lockwood, E.M. Williams-Hatala, B.A. Wood. Form, function and evolution of the human hand. *American Journal of Biological Anthropology*. 2023 Aug;181:6-57.

[11] N. Kamakura. Postures and movement patterns of the human hand: *A framework for understanding hand activity for clinicians and engineers. Universal-Publishers;* 2022 Jul 1.

[12] E. Difonzo, G. Zappatore, G. Mantriota, G. Reina. Advances in finger and partial hand prosthetic mechanisms. *Robotics*. 2020 Oct 1;9(4):80.

[13] C. Ziemian, M. Sharma, S. Ziemian. Anisotropic mechanical properties of ABS parts fabricated by fused deposition modelling. *Mechanical engineering*. 2012 Apr 11;23:159-80.

[14] C. Radu, M.M. Roşu, M. Iliescu. Design and Model of a Prosthesis for Hand. *InIOP Conference Series: Materials Science and Engineering 2020 Sep 1* (Vol. 916, No. 1, p. 012093). IOP Publishing.

[15] M.R. Aryal, S. Pun. Additive manufacturing of prosthetic hands: a brief overview. *International Journal on Interactive Design and Manufacturing (IJIDeM)*. 2022 Sep;16(3):1099-112.