3D Printing of Scaffolds for Medical Application using Digital Light Processing Technique

G. Shaikshavali [1*], G. Praveen Kumar Yadav[2], E. Venu Gopal Goud[3], K. Madhava Reddy[3] and Y.V.Mohan Reddy[3]

[1,2] Assistant Professor, Department of Mechanical Engineering, G. Pulla Reddy Engineering College, Kurnool, Andhra Pradesh, India
[3]Professor, Department of Mechanical Engineering, G. Pulla Reddy Engineering College, Kurnool, Andhra Pradesh, India
shaikshavali.vali@gmail.com

Abstract. A bone defect referred as absence of bone in its areas where it is typically present. Bone defects result from trauma, tumors, or infections. Bone defects frequently occur in conjunction with significant soft-tissue injuries, including those affecting muscles, tendons, and joints. The surgeon must address the soft tissues alongside correcting the bone defect, which can often be achieved through 3D printing techniques, to optimize the patient's functional outcome. Engineering bone tissue can facilitate the replacement of critical bone defects. Three-dimensional printing serves as an effective technology for the production of scaffolds essential in bone reconstruction. Various binders can produce bone scaffolds with the necessary mechanical strength. Currently, bone tissue engineering presents a novel approach for addressing bone abnormalities through the fabrication of porous bone scaffolds utilizing 3D printing technology. Designing materials for bone-tissue engineering which necessitates a comprehension of the anatomy and arrangement of natural bone tissue, along with the careful a selection of biomaterials, which may include polymers, bio ceramics, metals, and composites, that are either biomimetic or acceptable synthetic materials for the study of bone tissue engineering, scaffolds may be categorized as follows: polymeric, ceramic, composite, and metallic scaffolds, as well as structure-based lattices. The project utilizes two-unit cell scaffold structures: ISO Truss and Kelvin cell. The main aim of this project is 3D printing of scaffold structures using Digital light processing (DLP) technique using MED-WHT-10 material which contains bio compatible properties with complete set of mechanical properties are given per ISO and ASTM standards and testing the printed scaffolds for tensile, flexural and compression strength using INSTRON 3369

Keywords: 3D Printing; Scaffold; Bone; Bone defect; Digital Light Processing

1 Introduction

Human skeletons are made of living tissue called bones. Bones are formed with three types of tissues. Compact tissue is the outer tissue, which is harder; cancellous tissue

B. S. Babu et al. (eds.), *Proceedings of International Conference on Advanced Materials, Manufacturing and Sustainable Development (ICAMMSD-2024)*, Advances in Engineering Research 257,
https://doi.org/10.2991/978-94-6463-662-8_48

is sponge-like tissue that stays on the side of the bone. The ends of the bones are covered with subchondral tissue and cartilage. Human skeleton consists of 80 axial bones and 126 appendicular bones of various size and shape located in different parts of the body like head arms shoulders wrist legs ankles feet [1]. These bones provide support to human body and protects the internal organs. Bones also act as stores minerals which helps in development of blood cells. The human skeleton consists of 80 axial bones and 126 appendicular bones of various sizes and shapes located in different parts of the body, like the head, arms, shoulders, wrists, legs, ankles, and feet. These bones provide support for the human body and protect the internal organs. Bones also act as stores of minerals, which help in the development of blood cells [2].

Any abnormality in the structure and function of the bone can be concluded as bone defect. There are many reasons for these defects like accidental trauma, tumors, infections, degenerative diseases and so on, these defects can occur any bone or multiple bones in the skeleton [3,4]. Out of many defects three bone defects can be categorized as severe defects which may require reconstruction of the bone. In case of traumatic bone defects , infectious bone defects and tumor related defects surgeries re required to cut and reshape the bone, removal of tumors and dead bones and orthopaedic implants are required support the bone to heal properly.[5,6]

Bones may also be classified according to their shape. There are 5 major categories: 1. long-for example, the femur, humerus, radius; 2.short-the carpals and tarsus; 3. flat-for instance, the sternum, scapula; 4. Irregular-the mandible and vertebrae; 5. sesamoid-the patella [7]. One can easily recognize characteristic of long bones-osso longa-with its length, in comparison which is greater than the other dimensions. They principally appear in legs-for example, the humerus and radius. Lengthy bones establish the middle part, diaphysis, and with ends, distal epiphysis and proximal. Bone marrow has myeloid cavities and diaphysis [8]. Ossicular planar bones, often known as flat bones, have vast surfaces and are very thin, such as a scapula and pelvis. The size of the carpal bones and the tarsus are somewhat comparable in the short bones, also known as the ossus brevis. The body of a person with ossis multiforia or irregular bones may take on a variety of shapes. As a result, it is impossible to define them in three dimensions [9].

Femoral bone is the strongest bone and major bone in human body it supports the weight of body and facilitates various body movements it is also called femur and is located in thigh which connects hip joint and knee joint. The femoral bone, also known as the femur, which is strongest and longest bone in the body of human being. It is one of the major bones of the human skeleton and plays an essential part in maintaining the body's weight and aiding the body's movement. Various types of movements. The femur is located in the thigh, and it is the joint that links the knee joint to the hip joint. [10].

Advancements in the field of material science and technology have headed to the creation of various substitutes for bone repair and transplantation. Over the past few decades, materials that activate cells and genes, commonly referred to as bone-tissue engineering materials, have emerged as the third generation of bone-repair materials. The extracellular matrix scaffold has been developed using tissue engineering material [11].

The progenitor cell is capable of proliferating and differentiating along scaffolds to more accurately replicate the living circumstances of the tissue that is around the area. Bone regeneration scaffolds created using tissue engineering exhibit essential characteristics such as such as non-carcinogenicity, cost-effectiveness, non-toxicity, and biocompatibility, along with superior osteoinductive and osteoconductive properties.

Cellular scaffolds, gel foam, and Collagen sponge are all examples of biological scaffolds. Biological scaffolds also include corals, natural polymers and demineralized bone matrix. Among the components that make up synthetic scaffolds are synthetic polymers, porous metals, and calcium phosphates (CaPs). [12]. A significant part of mineral deposition and vascular ingrowth is played by collagen, and the provision of growth factors essential for bone regeneration. Due to the fact that its chemical makeup is quite similar to that of bone mineral, CaPs ceramics are an extremely popular choice for use as bone replacements. This feature promotes suitable stimulation of vascularization and proliferation of stem cells, while simultaneously promoting bone regeneration, in addition to this, without causing any local or systemic toxicity. The optimum materials for use are β-tricalcium phosphate (β-TCP) and hydroxyapatite (HAp) substrates among CaPs materials, attributed to their superior osteoconductive properties.

A few of the progressed approaches within the field of tissue engineering involves the process of facilitating the creation of a full bone transplant by the implantation of porous scaffolds that are paired with cell- as well as bone stimulating substances [13]. Tissue engineering scaffolds containing osteo inductive properties were employed to enhance bone regeneration by promoting the adhesion and proliferation of bone cells.

3D printing or Additive manufacturing technologies have evolved beyond mere prototyping and are now being utilized to produce a diverse range of products. A 3D printer is defined by three essential characteristics: it is three-dimensional, additive, and layer-based [14]. A variety of technologies designed for 3D printing has come into existence, each serving distinct functions. On the basis of the following criteria, the ASTM divided 3D printing technology into seven categories by way of printing, directed energy deposition, binding jetting, material extrusion, powder bed fusion, material jetting, vat photo polymerization and sheet lamination.

The Binder jetting 3D printing process involves the selective deposition of a powder particles are brought together by a liquid binding agent. In the technology of binder jetting the layer is created by spraying a chemical binder onto the powder that has been spread out. [15]. An application of the binder jetting technique involves the production of large-volume items from sand, raw sintered products and casting patterns. Binder jetting is capable of printing a wide variety of materials including ones like polymers, sands, metals, ceramics, and hybrids.

Directed energy deposition offers a great degree of control on the structure of the grain and has the ability to yield higher quality objects. a technique that involves the directly depositing energy operates on principles akin to material extrusion, utilizing an energy source to melt and deposit material onto a surface for the creation or repair of objects. However, the movement of the nozzle is not restricted to a particular axis and may occur in a number of different directions. Despite this, the method may be used to both polymers and ceramics. however, it is predominantly utilized with metals and metal-based hybrids, available in either wire or powder form [16]. Types of energy sources are laser-directed energy deposition, electron beam-directed energy deposition and Arc-directed energy deposition.

Technology for printing of materials using extrusion utilizes a filament made of thermoplastic material that is used continuously as its foundational element, the filament is fed from a coil via a moving heated printer extruder head, often referred to as an extruder, the process is low cost and can build fully functional model Material Extrusion can be done on a diverse range of materials, with thermoplastics being the most used. Examples include " Polylactic Acid (PLA), Acrylonitrile Butadiene Styrene (ABS), Thermoplastic PolyUrethane (TPU) High-Impact Polystyrene (HIPS), aliphatic PolyAmides (PA, commonly referred to as Nylon), and more recently, advanced plastics like lyEtherimide (PEI) and PolyEther Ether Ketone (PEEK)" have been used [17].

The material jetting technique makes use of inkjet-like nozzles to construct objects layer by layer. A nozzle passes through the build platform, releasing material in separate droplets. The material solidifies on the build platform as UV light hardens the layers of material [18]. A material that can dissolve is printed at the same time as the part to offer support, which is subsequently eliminated during the post-processing phase. A wide range of industries, including automakers, design firms, art studios, and medical organizations, utilize material jetting to produce reliable prototypes with exceptional accuracy. The substances employed in material jetting include alumina zirconia, waxes, and UV-cured resins.

The process of powder bed fusion encompasses a variety of approaches, including selective laser sintering (SLS), electron beam melting (EBM) and selective heat sintering (SHS). This method includes the use of both an electron beam or a laser in order to melt or join the material powder in a cohesive manner. [19]. The materials utilized in this process include metals, polymers ceramics, composites, and hybrids. The cooling rates of powder bed fusion can range from 10^3 to 10^8 K/s.

Vat photopolymerization represents a specific class of additive manufacturing processes that generate three-dimensional objects by precisely curing liquid resin via targeted light-activated polymerization. Common applications are observed in the medical and dental fields, with notable examples including surgical learning tools, facial prosthetics, and hearing aids [20]. Types of Vat photopolymerization Stereolithography (SLA) Two-photon polymerization (2PP) Digital Light Processing (DLP). A UV light source, like lasers or projectors, solidifies the resin incrementally, layer after layer. As build platform descends, allowing for the construction of additional layers above. The procedure goes on until the design reaches completion. The resin is extracted, and the component is detached.

2 Literature Work

There have been numerous attempts to categorize bone defects. We can categorize bone defects into a bigger number of more specialized groups or group defects that can be comparable into a small number of defects kinds.

An all-inclusive classification of bone deficiencies that encompasses all abnormalities of the tibia, femur, or patella. Both tibia and femur are classified as having four different kinds of abnormalities, while the patella is classified as having three different types. Intercalary flaws are a fourth type that may arise in the tibia and femur. Segmental defects, cavitary defects, and discontinuity defects can all occur in any of the three places. [21].

When it comes to the treatment of bone abnormalities, the use of autologous bone continues to be the gold standard. However, in order to minimize problems and morbidity at the donor places, bone replacements have become more popular. In the context of the treatment of bone abnormalities of the hand, the distal radius or the olecranon of the ulna have been the most often used locations for the harvesting of cancellous bone by means of surgical procedures [22].

Initially, bone substitutes for the treatment of hand bone defects had rarely been used currently, There is a growing number of research projects that are reporting their findings on this condition [23]. The effectiveness of a bone replacement is determined by whether it is made of natural or synthetic materials, if it promotes bone repair, and whether it displays a minimum of one of the subsequent features and characteristics: osteogenesis, osteo induction, or osteo conduction.

Most of the bones have the function of support. This is the basis of a human body being able to stay upright. The skeleton provides a scaffolding to the body, in specific to the muscles. Muscles, bones, and joints come together to create a lever system. The fulcrum is represented by the joints, the bones serve as the attachment point for the skeletal muscles, which operate as a lever, and the muscles are responsible for the generation of the motor power that is required in order to move [24].

The latter difference in structure between trabecular bone and cortical bone is reflected in very dissimilar mechanical properties. As a result of factors such as species, age, anatomical placement, liquid content, and other factors, the mechanical characteristics of bones are very diverse. This pattern is also mirrored in the bone's rigidity, reflecting the fact that the mineral content of a bone does not vary much with increasing age [25].

Periosteum, which is a connective tissue membrane, is the covering that gives bones their appearance. It is quite well vascularized. The outer layer, called fibrous periosteum, contains fibroblasts, while the inner one, called osteogenic periosteum, is made of progenitor cells equally they produce the bone tissue. They are responsible for the thickening of the bone, and the callus that forms on the faults in the bone structure may be filled up. [26].

The mechanical properties of bones depend on their material, structure, shape and size. There are two forms of mechanical and structural strength, each dynamically tuned to the system called locomotor. Pathological alterations may be fetched on by a reduction in physical activity, Inorganic elements, on the other hand, have elastic qualities and are associated with the activity of cells and the circulation of blood. Ischemia and deprivation can cause significant changes in mechanical properties [27].

Bones are exposed to various forces, including tension, compression, torsion, bending, and shear stress. Compression involves two forces, compressive and reaction, creating uniaxial compression. Bone tissue has a compressive strength that typically falls anywhere between 12.56 and 16.87 kg/mm2, which is quite close to the tensile strength. When subjected to compression forces, the mechanical strength of any given bone might vary, with patella, humerus, femur, and tibiae breaking down forces causing fractures [28]. Dry bone has a tensile strength of 10 kg/mm2, while newly formed compact bone has 12.41 kg/mm2. Cortical bone has greater stress and less deformation, Cancellous bone, on the other hand, has a greater potential for energy storage owing to the porous porosity of its structure. The elastic modulus of mature cortical bone is 18GPa when axial force application, 12 GPa,3.3 GPa when transverse and shear forces applied. Osteoporosis is a systemic illness that causes a loss of bone mass as well as micro architectural problems, which ultimately leads to a compromise in the structure of the bones. This reduction leads to increased resorption, initially in cancellous bones, and eventually in compact bones. Decreases in bone density of 0.7% per year are seen beyond the age of 30 [29].

The purpose of this comparative research on circular and spherical models in the making of bone tissue engineering scaffolds is to show the two designs with cylindrical & spherical pore structures that were built in Abaqus software. The ratio of pore size (L) to strut width (D) is the primary emphasis of this study. Finite element analysis (FEA) was utilized to conduct structural analyses encompassing torsion, compression and shear simulations. Compression experiments that were carried out on the scaffolds made of PPF created through projection micro stereolithography (PμSL) utilizing Digital Image Correlation (DIC) [30].

Evaluation of The design of the Ti6Al4V Primitive surface structure features a symmetrical gradient of pore size in a biomimetic bone scaffold, with the primary focus being the Primitive structure of TPMS. The artificial bone scaffold structure should exhibit excellent mechanical properties, adequate permeability, and facilitate cell adhesion and proliferation. This study involves the design and fabrication of multiple groups of Ti6Al4V Primitive models using selective laser melting (SLM). The mechanical properties of the scaffold are assessed through a mechanical compression test. The scaffold model's morphology is characterized. The scaffold's permeability was assessed and predicted through computational fluid dynamics (CFD) analysis [31].

Numerical investigation into the response of scaffoldings for bone subjected to torsional loading across various designs. The behaviour of scaffolds under torsional loads was investigated in this work. through the analysis of four distinct lattice-based architectures. The scaffolds were developed with three distinct porosities 60%, 75%, and 90%. Consequently, twelve variations of the scaffolds were developed. The shear modulus of all models was calculated using FEA analysis to determine how well they function when subjected to torsional strain. The findings indicated that in scaffolds exhibiting reduced porosity, the architecture of the scaffold does not significantly influence the shear modulus. In scaffolds exhibiting a porosity of 90%, When it came to scaffolds that had a porosity of 90 percent, the design of the scaffold had a substantial influence on the shear modulus. [32].

Investigation into the design and production of a scaffold for biomedical applications utilizing It is very essential to make the most of additive manufacturing for the regeneration of damaged tissue, as it possible in creating temporary structures that facilitate the growth of new tissue. These structures are referred to as scaffolds. The scaffold is required to offer temporary mechanical support within a tissue defect throughout the process of tissue regeneration. The scaffolds exhibit three-dimensional porous architectures [33]. This porous scaffold featuring an interconnected network is essential for facilitating cell attachment and growth. It is more generally known as 3D printing, which stands for additive manufacturing, represents a groundbreaking technology that enables the direct construction of intricate physical prototypes from 3D-CAD models. This material finds extensive application across various fields, particularly in the medical domain, including tissue engineering.

3D printing of computationally planned lattices through optimized properties for tissue engineering A computational method was created to model scaffolds featuring lattice structures across eight distinct topologies, while evaluating properties pertinent to applications in bone tissue engineering. The properties evaluated encompass the permeability, the porosity, the pore size, the surface-volume ratio, the elastic modulus, and the shear modulus [40]. The patterning of beam-based unit cells was used to generate lattice topologies. Design characteristics such as beam diameter and unit cell length were included into the patterning process. Different topologies were subjected to simulations that were carried out using finite element techniques, measuring the relationship between shear modulus and elastic modulus with porosity, as well as the scaling of permeability with porosity cubed relative to the square of the surface-volume ratio. A comparison of lattices was conducted, focusing on controlled properties associated with pore size and porosity. Comparative analyses indicate that lattice topology results in unique specializations regarding achievable properties.

An investigation on the use of DLP for microstructure control in three-dimensional printing. Digital light processing and stereolithographic represents a significant advancement in 3D printing field. Nonetheless, it provides minimal influence over the exterior aesthetics of the printed article. The printing process generally involves layering, resulting in aliasing artefacts that influence the surface appearance [34]. An option for antialiasing involves utilizing the values of the grayscale pixels in the layer pictures that were sent to the printer. This facilitates a form of sub voxel growth regulation. This conception is examined and applied for the purpose of modifying surface microstructure. To put it differently, A greyscale pattern is applied to the surface voxels of a printed item before the cross-sectional layer pictures are sent to the printer. This allows us to improve the surface properties of the printed product. The employment of a smooth noise function has been shown to be an efficient technique for modifying the surface roughness and breaking the regular patterns that are responsible for aliasing. On the other hand, we provide instances that illustrate regularities in order to accomplish the goal of achieving a regulated anisotropic surface look. We aspire that the control of sub voxel growth in stereolithographic will advance 3D printing towards the ability to customize surface appearance.

The field of dentistry has adopted 3D printing technology for the creation of dental crowns, dental bridges, dental braces, and dental aligners. This technology makes it possible to create dental devices in a precise and speedy manner, therefore reducing the amount of time that patients spend sitting in the doctor's office and improving their oral health in general. The advent of 3D printing has opened new avenues for creating customized drug delivery systems, specifically designed to meet the unique requirements of individual patients. Furthermore, professionals in the pharmaceutical field Make use of three-dimensional printing in order to create intricate pharmacological compositions and dosage forms that have precise release profiles. 3D printing has significantly advanced the field by facilitating the development of intricate models, laboratory apparatus, and microfluidic devices. It is through the use of this technology that improvements in drug discovery, illness modeling, and the understanding of biological processes are produced [35]. There have been a number of unique advances that have marked the transition of 3D printing into the biomedical arena. These innovations have the potential to alter healthcare practices and medical inquiry.

The use of 3D printing in prosthetics and orthopaedics has led to more personalization and innovation. This innovative approach enables customized prosthetics and bone replacements for each patient. Following the latest software and 3D printing, tailored orthopaedic implants to treat. Complex surgeries are becoming more popular. In orthopaedics, 3D printing has transformed technique to bone replacement Tradition implants may not match precisely with a patient's anatomy, causing discomfort and difficulties [36]. Using 3D printing, orthopaedic. Surgery can create implants that are a good fit for the bone structure of the patient. Improving implant integration, post-operative complications, and patient outcomes are all possible with this individualized approach. Increases in the use of 3D printing have greatly impacted in orthopaedics, especially in understanding complex bone fracture patterns, simplifying surgery and guaranteeing precise implant placement in preclinical studies. In orthopaedics, many implants are accessible for standardization. operations to replace bones in various bodily parts. Nevertheless, Standardized implants may not be effective in non-traditional cases with patients with deviating bone geometries. typical implant uses for size or disease-related needs Salvage procedures and arthrodesis are usually recommended, but with a low success rate. Hip surgery has a lower success rate and patient satisfaction [37].

3 Methodology

3D printing using Digital Light Processing Technique is being used to print Scaffold, DLP 3D printers enable the creation of exceptionally precise tissue and organ models, driving progress in individualized medical treatments. Digital Light Processing (DLP) is a method for creating three-dimensional objects that employs a digital projector to precisely cure a photopolymer resin in layers. DLP stands out as a favoured method for creating scaffolds, thanks to its impressive resolution and rapid printing capabilities. The following outlines the procedure for utilizing DLP in scaffold generation

A photopolymer resin suitable for DLP printing has been formulated. The composition of the resin generally includes a blend of acrylate monomers, photo initiators, and various additives. The resin that has been prepared is positioned in a vat and subjected to the illumination of a digital light projector. The projector solidifies the resin in a specific pattern, building the part layer after layer as shown in figure 1.

The distinctive capability of DLP to project complete layers at once results in a considerable increase in speed, which is a crucial benefit, particularly for extensive production runs. DLP provides a higher quality surface finish than FDM, resulting in reduced post-processing and a more polished final product. Although the upfront expenses for setup and resin can be significant, the increased printing speed can lead to a reduced cost per part in large-scale manufacturing. DLP 3D printers provide various settings that can be fine-tuned to enhance your prints, including layer thickness, exposure duration, and lift speed. The condition of your resin tank has an immediate influence on the quality of the 3D prints you produce. The positioning of your model can influence the quality of your print as well as the lifespan of your printer.

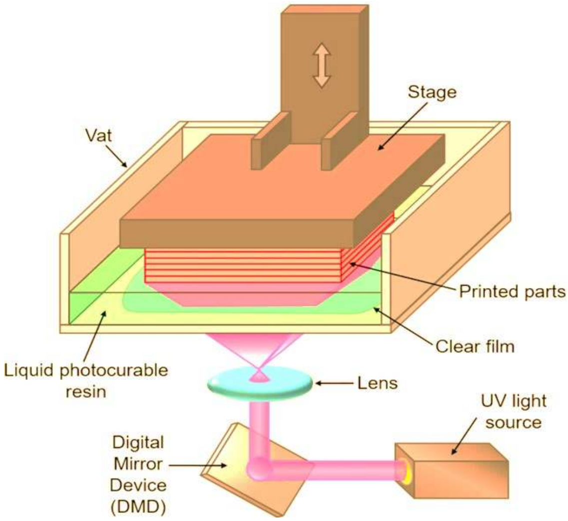

Fig. 1. Shows working principle of DLP Printing process

Once the printing process is finished, the printed parts might need additional steps like cleaning, curing, and sterilization to enhance its compatibility with biological systems and its mechanical characteristics. DLP presents numerous benefits compared to alternative 3D printing methods, including superior printing resolution, rapid printing speed, and the capability to produce complex and detailed designs. The benefits of DLP position it as a compelling method for scaffold creation in the fields of tissue engineering and regenerative medicine. The 3D printing was preformed using Digital light processing machine in the following steps as shown in figure 2.

- The 3D models of scaffold structures were obtained from Creo CAD software in step file format.
- The step files are converted in to STL Files using create bot software. Where the cad model is analyzes and printing orientation and other parameters like print thickness and exposure time of light to resin is set for the machine. Layer thickness = 100 microns, exposure time = 10sec.
- MED -WHT 10 material in the resin form is obtained from Form labs company and used for 3D printing the liquid resin is verified and poured in the resin chamber.
- As per the CAD model the printing takes place layer by layer by exposing resin to to a digital light projector. The projector cures the resin in the desired pattern, solidifying the resin layer-by-layer to create the give model.
- After the printing is completed, the Printed work piece is exposed to UV light for curing and sterilization to improve mechanical properties.
- All the work pieces of both scaffold structures ISO truss and KELVIN truss are obtained by following the above given steps.

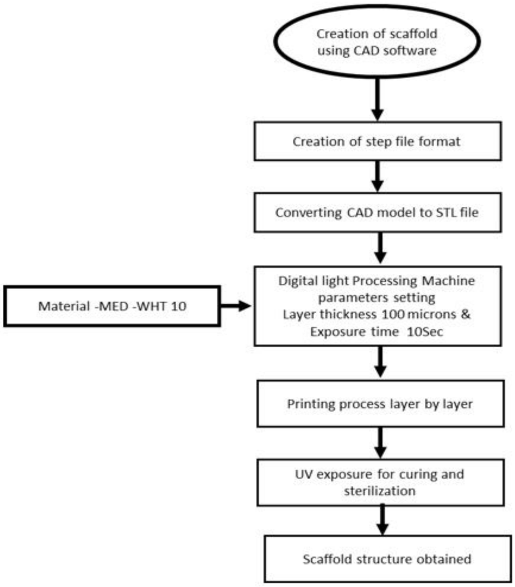

Fig. 1. Showing scaffold 3D printing process

3.1 Materials selection and Preparation

The selection of raw materials for the three-dimensional printing of bone tissue scaffolds is contingent upon the specific properties needed for the intended application, including factors like biocompatibility, mechanical strength, and deterioration rate.

Med White 10 resin is a photopolymer resin frequently utilized in the 3D printing of bone tissue scaffolds. This material is compatible with biological systems and can be solidified through the application of a light source, like a UV laser or LED, resulting in a durable structure. Med White 10 is a bioresorbable ceramic material frequently utilized in applications related to bone tissue engineering. This material consists of tricalcium phosphate (TCP) and magnesium oxide (MgO), both of which are biocompatible and may be metabolized and excreted by the body over time. It exhibits excellent compatibility with biological systems and does not provoke a negative immune reaction, thereby minimizing the likelihood of rejection. It possesses properties that facilitate the ingrowth of bone tissue and can be engineered to release growth factors or medications to enhance the process of bone regeneration. Moreover, Med White 10 possesses a porous structure that facilitates the ingrowth of blood vessels and the migration of cells. This has the potential to enhance the healing process of bone tissue in regions affected by defects.

The scaffold is usually crafted with the aid of computer-aided design (CAD) software, enabling meticulous management of the scaffold's dimensions, form, and internal structure. The design must be refined to ensure it delivers the required mechanical strength and biological compatibility for its intended use.

3.2 Scaffold Preparation

In the present study scaffolds with lattice structures are prepared as to be used as bone piece replacement to support the defected bone as the scaffold and lattice structure will aid in tissue growth in scaffold and gives required strength to the bone

Bone tissue scaffolds are intricate three-dimensional frameworks designed to assist in the repair or regeneration of damaged bone tissue. These are usually constructed from materials that are compatible with biological systems, resembling the characteristics of natural bone tissue, and can be engineered to offer structural support while encouraging the development of new bone cells.

Lattice structures can be categorized into periodic or random (stochastic) based on their arrangement patterns. Lattice structures are typically categorized based on the type of porosity (open or closed) and the order of their building unit cells (stochastic or non-stochastic). Examples include foam, honeycomb, sponges, and folded materials. Lattice structures feature open pores and exhibit non-random orientations of the constituent unit cells. The geometry and topology of the unit cell are utilized to customize the mechanical properties of the component [40]

The classification of lattice structures utilized in tissue engineering and bone scaffolds typically depends on the design of the unit cells. This design can be categorized into four distinct groups: Computer-aided design, visual representation, hidden surfaces, or optimized structural elements [41]. Cells according to architecture Various architectures of lattice structures are Strut-based lattice cells, Skeletal- and sheet-triply periodic minimal surfaces (TPMS). in the current study

Scaffold are prepared using two different Strut based lattice. Iso Truss lattice and Kelvin truss.

An iso-truss unit cell represents a structural lattice design frequently utilized in the creation of bone tissue scaffolds. The term "iso-truss" indicates that the structure possesses uniform strength across all directions. Iso-truss features a significant surface area-to-volume ratio, facilitating efficient nutrient and oxygen diffusion to the cells embedded in the scaffold. The iso-truss lattice structure exhibits significant porosity, facilitating the diffusion of nutrients and promoting tissue generation within the scaffold.

The Kelvin truss unit cell serves as a compelling option for bone tissue scaffolds due to its optimal combination of mechanical strength, porosity, and biocompatibility. The Kelvin truss unit cell is a three-dimensional lattice structure characterized by its eight identical strut members, creating a cube-like form with diagonal bracing elements.

Details on the design parameters for the lattice structure are outlined below, and the ratio of the cross-sectional circular radius to the length of the cube edge (r/s) was calculated for each unit cell. The nominal dimensions of Lattice-structured cubes are 3 mm × 3 mm × 3 mm of both Iso truss and Kelvin truss. Lattice cells joined together forms a scaffold structure. As shown in figure 3

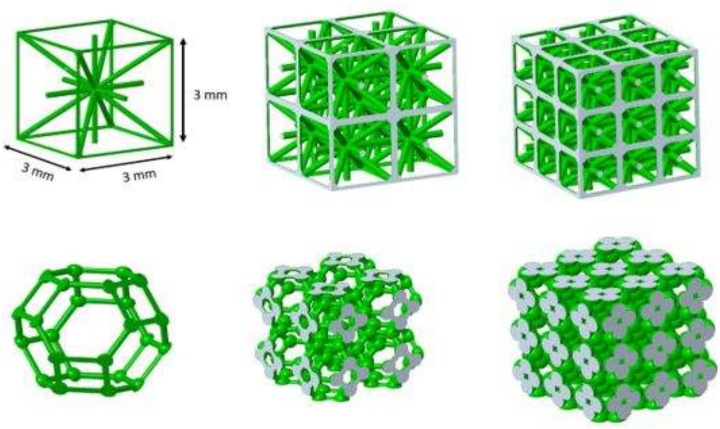

Fig. 2. . Showing Lattice to scaffold formation for Iso truss and Kelvin truss

Design and 3D printing of porous scaffolds with different lattices structure using Digital light processing. The 3D models of scaffold structures were obtained from Creo CAD software in step file format. The step files are converted in to STL Files using create bot software. Where the cad model is analyses and printing orientation and other parameters like print thickness and exposure time of light to resin is set for the machine. Layer thickness = 100 microns, exposure time = 10sec.

MED -WHT 10 material in the resin form is obtained from Form labs company and used for 3D printing the liquid resin is verified and poured in the resin chamber. As per the CAD model the printing takes place layer by layer by exposing resin to a digital light projector. The projector cures the resin in the desired pattern, solidifying the resin layer-by-layer to create the give model.

After the printing is completed, the Printed workpiece is exposed to UV light for curing and sterilization to improve mechanical properties. All the workpieces of both scaffold structures ISO truss and OCTE truss are obtained by following the above given steps.

Fig. 3. showing Digital Light Processing Machine

4 EXPERIMENTAL RESULTS

To gain insight into scaffolds, it is essential to examine their structural response and integrity. This encompasses the assessment of physical properties related to functional characteristics. The mechanical characteristics of the scaffolds are determined through tensile testing, flexural testing, and compressive testing of the specimens. The subsequent details outline the methodology and apparatus utilized for conducting the tests

4.1 Tensile Test

Tensile test is one of the mechanical tests of the scaffolds to know the strength of the scaffold. ASTM D638 standard is used to compute the tensile strength of the scaffold.

The scaffold was 3D printed with dimensions according to ASTM D638 as shown in figure 5. The tensile test is performed in a Universal testing machine (INSTRON 3369) which is connected to the computer to get the values accurately for testing standard test specimens, a typical test speed is 2 mm/min.

The tests were conducted on both the Iso truss and Kelvin truss specimens The tensile specimen is placed in between the grips of a Universal Test Machine and the load is given gradually until the specimen fails.

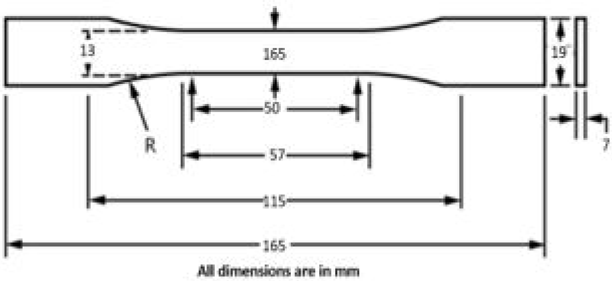

Fig. 4. Tensile specimen dimensions as per ASTM D638

Fig. 5. Iso truss lattice structured tensile specimen and Instron 3369 UTM

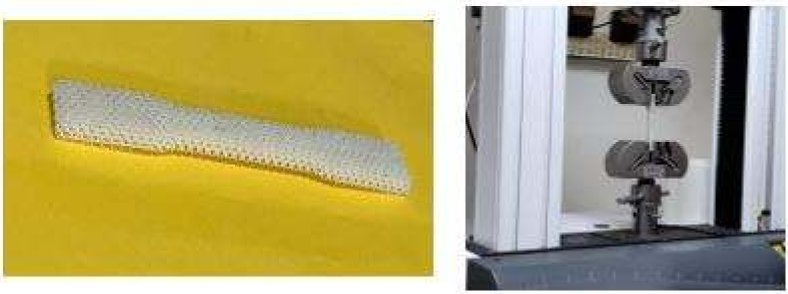

Fig. 6. Kelvin truss lattice structured tensile specimen and Instron 3369 UTM

Table 1. Tensile test results

Specimen	Max Load (N)	Load at Break	Tensile Test at Maximum Load (MPa)	Modulus (automatic Young's) (MPa)	Tensile Strain atbreak (mm/mm)
Iso Truss	587.39	587.37	19.58	277.59	0.07683
Kelvin Truss	236.53	236.53	7.88	107.05	0.06743

It can be seen from the above table1. The maximum load Iso truss lattice scaffold can with stand before breaking is 587.39 N with young's modulus of 277.59 MPa and maximum load Kelvin truss lattice scaffold can with stand before breaking is 236.53 N. with young's modulus of 107.05 MPa It can be observed that the Iso Truss Scaffold is able to bear a higher maximum tensile load than the Kelvin truss Scaffold printed with Med White10 resin. The printed samples and tensile test setups can be seen from figure 6, 7.

4.2 Flexural Test

Flexural strength or fracture strength. Tests were performed to check if the 3D printed Scaffold structure can with stand deformation under load. A three-point flexural test is used to test flexural strength in this test the specimens are place on a three-point bend fixture and testing has been done on Instron 3369 universal testing machine by applying the load gradually. The test sample used in the flexural test measured 130 x 12.7 x 3.2 mm and in accordance with ASTMD 730. The samples were 3D printed using digital light processing technique in both Iso truss and Kelvin truss lattice structures.

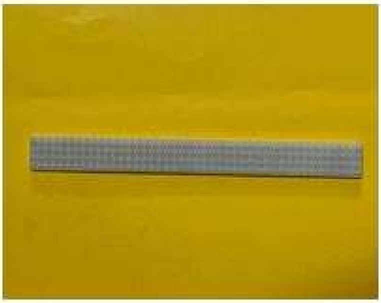

Fig. 7. Iso truss lattice structured flexural test specimen and Instron 3369 UTM

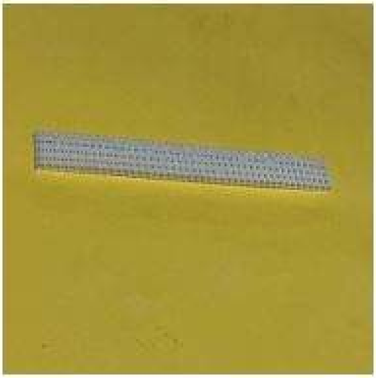

Fig. 8. Kelvin truss lattice structured flexural test specimen and Instron 3369 UTM

Table 2. Flexural test results

Specimen Label	Maximum Load (kN)	Maximum Stress (MPa)	Flex Modulus (MPa)
Iso Truss	0.04	21.44	1026.75
Kelvin Truss	0.01	3.56	119.77

It can be seen from the above table 2. The maximum load Iso truss lattice scaffold can with stand before breaking is 40N with flexural modulus of 1026.75 MPa and maximum load Kelvin truss lattice scaffold can with stand before breaking is 10 N. with flexural modulus of 119.77 MPa It can be observed that the Iso Truss Scaffold has more resistance to deformation under load when compared to Kelvin truss Scaffold printed with Med White10 resin. The printed samples and flexural test setups can be seen from figure 8, 9.

4.3 Compressive Test

Compressive testing was performed to determine the compressive strength of lattice scaffold. A compressive force is exerted on the scaffold sample positioned between two platens until it fractures. Compression tests specimens were 3D printed using DLP technique according to dimensions of standard ASTM D965. The specimen dimensions are 12.7 in square and 25.4 in length as shown in figure 8.

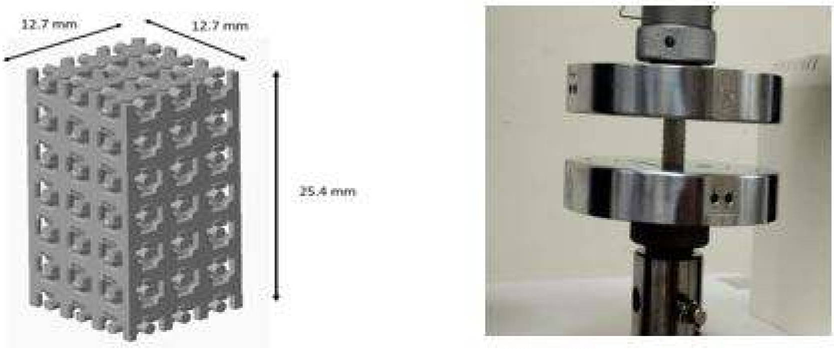

Fig. 9. Iso truss lattice structured Compression test specimen and Instron 3369 UTM

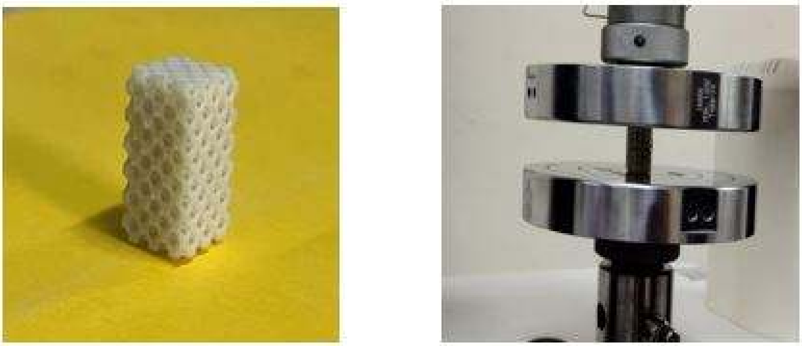

Fig. 10. Kelvin truss lattice structured Compression test specimen and Instron 3369

Table 3. Compressive test results

Specimen Label	Maximum Load (kN)	Compressive Stress (MPa)	Modulus (MPa)
Iso Truss	2.05	16.53	945.04
Kelvin Truss	1.95	15.41	687.52

It can be seen from table 3. The maximum load Iso truss lattice scaffold can with stand before breaking is 2.05KN with Compressive modulus of 945.04 MPa and maximum load Kelvin truss lattice scaffold can with stand before breaking is 1.95KN. with Compressive modulus of 687.52 MPa It can be observed that the Iso Truss Scaffold has more compressive strength when compared to Kelvin truss Scaffold printed with Med White10 resin. The printed samples and Compression test and setups can be seen from figure 10, 11.

5 Conclusions

Bone abnormality caused either by structure damage or function loss of bone. As bone damages are very frequent due to many reasons these defects need to be treated and it is being treated with plates rods and pins made of metals. There is a need for a material which are bio compatible and structure which allow growth of cancellous tissue so as to repair the damaged bone. To replicate the structure of genuine bone tissue, three-dimensional constructs known as bone scaffolds were created. bone scaffolds help to promote bone regeneration.

AM methods, unlike traditional manufacturing processes, display orthotropic behaviour, with complicate product design. Vat Photopolymerization is an additive manufacturing technique also known as Digital light processing. The process of photopolymerization entails a chemical reaction where light initiates the polymerization.

In present work scaffolds are designed using Iso truss unit cell and Kelvin truss unit cell with the help of Creo parametric software according to the test specimen sizes for the compression, tensile and flexural tests. The material used for the printing of scaffolds is med white 10 which contains more bio- compatible properties than other materials along with full suite of mechanical properties as per the ASTM and ISO standards.

The scaffolds are printed using digital light processing technique (DLP) by which we get more precision and accurate scaffold structures. The printing parameters used for printing scaffold are layer thickness 100 microns and UV exposure time is set for 10 Seconds. The scaffolds are printed in the shape of the test specimens as per ASTM standards.

Mechanical properties of the printed specimens were tested for compression, tensile, and flexural tests using INSTRON 3369. From the results it can be seen that out of two structures Iso and Kelvin trusses Iso truss exhibit better tensile, flexural and compression strengths.

References

1. Engh, G. A. (n.d.). Classification of Bone Defects Femur and Tibia HISTORICAL REVIEW OF BONE DEFECT CLASSIFICATION SCHEMES.
2. Bruno, R.J.; Cohen, M.S.; Berzins, A.; Sumner, D.R. Bone graft harvesting from the distal radius, olecranon, and iliac crest: A quantitative analysis. J. Hand Surg. Am., 26, 135–141. (2001)
3. Vyrva, O.; Thirkannad, S.M. Distal Radius Bone Graft From the Second Extensor Compartment: A Safe and Effective Technique. Tech. Hand Up. Extrem. Surg., 20, 147–150. (2016)
4. Liodaki, E.; Kraemer, R.; Mailaender, P.; Stang, F. The Use of Bone Graft Substitute in Hand Surgery. A Prospective Observational Study. Medicine, 95, e3631. (2016)
5. Yamada, H., & Evans, F. G.: Strength of biological materials, (1970).

6. Van Rietbergen, B., Odgaard, A., Kabel, J., & Huiskes, R.: Direct mechanics assessment of elastic symmetries and properties of trabecular bone architecture. *Journal of biomechanics*, *29*(12), 1653-1657, (2004).
7. Bartel, D. L., & Davy, D. T.: *Orthopaedic biomechanics: mechanics and design in musculoskeletal systems*. Prentice Hall, (2006).
8. Putzier M, Strube P, Funk JF, et al. Allogenic versus autologous cancellous bone in lumbar segmental spondylodesis: a randomized prospective study. Eur Spine J;18:687-695. (2009)
9. Lenze U, Pohlig F, Knebel C, et al. Autologous fibula transplantation for reconstruction of bone defects. Orthopade;46:648-655. (2017)
10. Fillingham Y, Jacobs J. Bone grafts and their substitutes. Bone Joint J;98-B(Suppl A):6-9. (2016)
11. Nudelman F, Pieterse K, George A, et al. The role of collagen in bone apatite formation in the presence of hydroxyapatite nucleation inhibitors. Nat Mater;9:1004-1009. (2010)
12. Xu, B., Lee, K. W., Li, W., Yaszemski, M. J., Lu, L., Yang, Y., & Wang, S.. A comparative study on cylindrical and spherical models in fabrication of bone tissue engineering scaffolds: Finite element simulation and experiments. Materials and Design, 211, Article 110150. (2021)
13. Mazzoli A. Selective laser sintering in biomedical engineering. Med Biol Eng Comput.;51: 245–56.(2013)
14. Boland T, Wilson WC Jr, Xu T, inventor; Clemson University, assignee. Ink-jet printing of viable cells. United States patent US 7051654. May 30. (2006)
15. Zuniga JM, Peck J, Srivastava R, Katsavelis D, Carson A. An open source 3D-printed transitional hand prosthesis for children. J Prosthet Orthot.;28:103–8 (2016)
16. Afizah Ibrahim ,N Sa'ude ,M Ibrahim , " Optimization of Process Parameter for Digital Light Processing (DLP) 3d Printing " , *International Journal of Mechanical and Production Engineering (IJMPE)* , pp. 116-119, Volume-5,Issue-6. (2017)
17. Barcik J, Ernst M, Schwyn R, Freitag L, Dlaska CE, Drenchev L, et al. Development of surgical tools and procedures for experimental preclinical surgery using computer simulations and 3D printing. Int J Online Biomed Eng.;16:183–95.(2020).
18. Kantaros, A.; Piromalis, D. Employing a Low-Cost Desktop 3D Printer: Challenges, and How to Overcome Them by Tuning Key Process Parameters. Int. J. Mech. Appl., 10, 11–19. (2021).
19. Dilberoglu UM, Gharehpapagh B, Yaman U, Dolen M. The role of additive manufacturing in the era of Industry 4.0. Procedia Manuf.;11:545–54 (2017)
20. Luo Z, Zhang H, Chen R, Li H, Cheng F, Zhang L, et al. Digital light processing 3D printing for microfluidic chips with enhanced resolution via dosing- and zoning-controlled vat photopolymerization. Microsyst Nanoeng.;9:103.(2023)
21. Killington K, Mafi R, Mafi P, Khan W. A systematic review of clinical studies investigating mesenchymal stem cells for fracture non-union and bone defects. Curr Stem Cell Res Ther 2017 (Epub ahead of print) PMID: 28914208. (2021).
22. W.T. Shi, Y.D. Que, X. Zhang, L. Bian, X.J. Yu, X. Tang, G.F. Yang, Y. Dai, S.Q. Bi, D. M. Lv, Y.Y. Weng, W.J. Wu, Z.J. Zhang, X.J. Lu, N.Y. Lu, Functional tissue engineered bone-like graft made of a fibrin scaffold and TG2 gene-modified EMSCs for bone defect repair, NPG Asia Mater. 13 (1) (2021).
23. J.L. Milan, J.A. Planell, D. Lacroix, Simulation of bone tissue formation within a porous scaffold under dynamic compression, Biomech. Model. Mechanobiol. 9 (5) 583–596(2010)

24. Egan PF, Gonella VC, Engensperger M, Ferguson SJ, Shea K Computationally designed lattices with tuned properties for tissue engineering using 3D printing. PLOS ONE 12(8): e0182902. (2017)
25. Nakamura M, Iwanaga S, Henmi C, Arai K, Nishiyama Y. Biomatrices and biomaterials for future developments of bioprinting and biofabrication. Biofabrication.;2:014110. (2010)
26. Catros S, Fricain JC, Guillotin B, Pippenger B, Bareille R, Remy M, et al. Laser-assisted bioprinting for creating on-demand patterns of human osteoprogenitor cells and nano-hydroxyapatite. Biofabrication.;3:025001. (2011)
27. Eshraghi, S.; Das, S. Mechanical and microstructural properties of polycaprolactone scaffolds with one-dimensional, twodimensional, and three-dimensional orthogonally oriented porous architectures produced by selective laser sintering. Acta Biomater.,6, 2467–2476. (2010)
28. Eshraghi, S.; Das, S. Mechanical and microstructural properties of polycaprolactone scaffolds with one-dimensional, twodimensional, and three-dimensional orthogonally oriented porous architectures produced by selective laser sintering. Acta Biomater., 6, 2467–2476. (2010)
29. Derby B. Printing and prototyping of tissues and scaffolds. Science.;338:921–6. (2012)
30. Wang, S., Shi, Z., Liu, L., Zhou, X., Zhu, L., & Hao, Y.. The design of Ti6Al4V Primitive surface structure with symmetrical gradient of pore size in biomimetic bone scaffold. Materials and Design, 193. (2020)
31. Ali, D. (2020, November 19). The Behaviour of Scaffolds for Bone under Torsional Loading with Different Architectures; A Numerical Analysis. TIPTEKNO 2020 - Tip Teknolojileri Kongresi - 2020 Medical Technologies Congress, TIPTEKNO (2020).
32. Siva, L., Krishna, R., Kamal, M., Venkatesh, S., & Manmadhachary, A.. DESIGN AND MANUFACTURING OF A SCAFFOLD FOR BIOMEDICAL APPLICATIONS USING ADDITIVE MANUFACTURING. Indian J.Sci.Res, 15(2), 1–06. (2017)
33. Luongo, A., Falster, V., Doest, M. B., Ribo, M. M., Eiriksson, E. R., Pedersen, D. B., & Frisvad, J. R.. Microstructure Control in 3D Printing with Digital Light Processing. Computer Graphics Forum, 39(1), 347–359. (2020)
34. Xu, B., Lee, K. W., Li, W., Yaszemski, M. J., Lu, L., Yang, Y., & Wang, S.. A comparative study on cylindrical and spherical models in fabrication of bone tissue engineering scaffolds: Finite element simulation and experiments. Materials and Design, 211. (2021)
35. Shuai, C.; Mao, Z.; Lu, H.; Nie, Y.; Hu, H.; Peng, S. Fabrication of porous polyvinyl alcohol scaffold for bone tissue engineering via selective laser sintering. Biofabrication, 5, 015014 (2013).
36. Schlegel L, Ho M, Fields JM, Backlund E, Pugliese R, Shine KM. Standardizing evaluation of patientspecific 3D printed models in surgical planning: development of a cross-disciplinary survey tool for physician and trainee feedback. BMC Med Educ.;22:614, (2022)
37. Bozkurt Y, Karayel E. 3D printing technology; methods, biomedical applications, future opportunities and trends. J Mater Res Technol. 2021;14:1430–50.
38. Kantaros, A.; Giannatsis, J.; Karalekas, D. A novel strategy for the incorporation of optical sensors in Fused Deposition Modeling parts. In Proceedings of the International Conference on Advanced Manufacturing Engineering and Technologies, Stockolm, Sweden, 27–30 October 2013; Universitets service US AB, KTH Royal Institite of Technology: Stockholm, Sweden, (2013).

39. Willie BPA, Schmidt-Bleek K, Cipitria A, et al. Designing biomimetic scaffolds for bone regeneration: why aim for a copy of mature tissue properties if nature uses a different approach? Soft Matter;6:4976. (2010)
40. A. Yanez, A. Cuadrado, O. Martel, H. Afonso, D. Monopoli, Gyroid porous titanium structures: a versatile solution to be used as scaffolds in bone defect reconstruction, Mater. Design.
41. Bandhu, D., Djavanroodi, F., Shaikshavali, G., Vora, J. J., Abhishek, K., Thakur, A., Kumari, S., Saxena, K. K., Ebrahimi, M., & Attarilar, S. (2022, September 26). Effect of Metal-Cored Filler Wire on Surface Morphology and Micro-Hardness of Regulated Metal Deposition Welded ASTM A387-Gr.11-Cl.2 Steel Plates. *Materials*, *15*(19), 6661. https://doi.org/10.3390/ma15196661 (2022)