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SYSTEMATIC LITERATURE REVIEW ON THE APPLICATION OF ADDITIVE MANUFACTURING IN REPAIR AND RESTORATION

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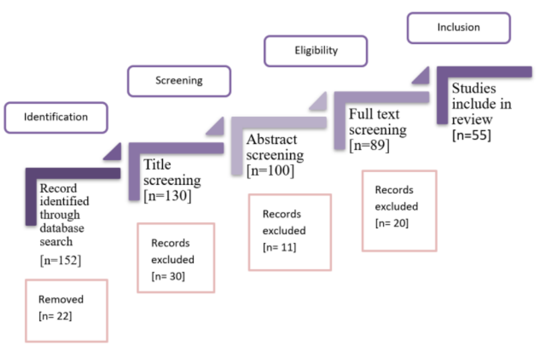
Graphical abstract



Abstract

The process of repair and restoration is crucial to environmental sustainability as it allows parts or products to be reinstated like a new condition before moving on to the next stage of their life cycles. Presently, skilled workers manually do these tasks. With the introduction of additive manufacturing (AM), people are exploring its possibilities for automated repair and restoration, making it a more efficient technique for remanufacturing. This systematic review aims to identify the application of AM specifically in repair and restoration. The search was carried out using all accessible electronic databases. 75 articles were found that fulfilled the search criteria. The gap in each article was discovered, to provide comprehensive coverage of repairing techniques of parts made of the same or different materials. The findings show that AM technology heralds a new era of repairability. Using AM for repair and restoration shows promising results, motivating more research. In addition, AM shows transformational potential for creating, making, distributing, and repairing goods. Printing replacement components is an example of a step toward this transition. AM provides a rapid and effective repair solution when product malfunctions and specific replacement components are unavailable or limited.

Keywords: Systematic literature review, additive manufacturing, repair, restoration, remanufacturing

Abstrak

Proses pembaikan dan pemulihan adalah penting untuk kelestarian alam sekitar kerana ia membolehkan komponen atau produk dipulihkan seperti keadaan baharu sebelum beralih ke peringkat seterusnya dalam kitaran hayatnya. Dengan pengenalan pembuatan tambahan (AM), orang ramai menggunakannya untuk pembaikan dan pemulihan automatik, menjadikannya teknik yang lebih cekap untuk pembuatan semula. Kajian literatur sistematik ini bertujuan untuk mengenal pasti aplikasi AM khususnya dalam pembaikan dan pemulihan. Pencarian dilakukan menggunakan semua pangkalan data elektronik yang boleh diakses. 75 artikel didapati memenuhi kriteria carian. Jurang dalam setiap artikel telah ditemui, untuk menyediakan liputan komprehensif mengenai teknik pembaikan yang diperbuat daripada bahan yang sama atau berbeza. Penemuan menunjukkan bahawa teknologi AM menandakan era baharu kebolehbaikan. Menggunakan AM untuk pembaikan dan pemulihan menunjukkan hasil yang menjanjikan, memotivasikan lebih banyak penyelidikan. Di samping itu, AM menunjukkan potensi transformasi untuk mencipta, membuat, mengedar dan membaiki barangan. Mencetak komponen gantian ialah contoh langkah ke arah peralihan ini. Apabila kerosakan produk dan komponen gantian khusus tidak tersedia atau terhad, AM menyediakan penyelesaian pembaikan yang cepat dan berkesan.

Kata kunci: Kajian literatur sistematik, pembuatan tambahan, pembaikan, pemulihan, pembuatan semula

1.0 INTRODUCTION

In a circular economy, the repair is crucial in "slowing the flow" of items. To increase the accessibility of spare parts, original equipment manufacturers (OEMs) must devise efficient systems of storing components for discontinued goods [1]. One possible replacement for stockpiling is on-demand production using techniques like additive manufacturing [2,3]. Three-dimensional printing ensures that these components can be obtained even after storage is no longer viable [4]. Repair times, personnel expenses, storage expenses, material usage, and transportation costs are all things that may be minimized with 3D-printed spare parts.

Digital fabrication, or additive manufacturing (AM), employs successive material addition to create physical objects from a geometrical representation. AM is the process of layering engineering materials to construct the needed component from 3D model data [5]. It is a multidisciplinary strategy that combines materials science, structural engineering, mechanical engineering, and software engineering.

Charles Hull designed the stereolithography machine in 1986. Hull's 3D Systems soon specialized in stereolithography and other patents. In 1988, Scott Crump invented fused deposition modelling (FDM). A year later, he and his wife, Lisa Crump, created Stratasys on FDM [6].

Printed materials using AM technology include traditional thermoplastics, ceramics, graphene-based materials, composites, and metal. Its capacity to create bespoke components on demand has contributed to its increased appeal in the last decade. In terms of different techniques and materials, a wide range of 3D printers are available [7]. Since their inception about four decades ago, 3D printers have intrigued the attention of various disciplines, been used in several applications, and revolutionized the way we think about production [5].

Before the advent of the concept of disability and the subsequent industrial revolution, most people lived their lives as producers. We now buy things that people used to manufacture while they used to fix the things that we tossed away [8]. Our relationship with material things has undergone profound change and is today fraught with difficulties [9]. On the other hand, grassroots movements and cultures like the maker movement, DIY culture, open design, and repair cafés give the impression that we are on the cusp of a paradigm change in terms of the way we approach the mending of relationships as well as physical objects [9].

Even though the primary use of a 3D printer in product design is prototyping, it is now possible to produce a broad range of objects, including houses, bicycles, vehicles, and even organs, using live cells as an unprocessed substance [10]. Engineers and academicians may use a 3D printer in nearly every sector. This review aims to explore the opportunities and barriers of 3DP through understanding repair activity. The uniqueness of interaction between the product and the individual can only be understood if the method enables the meaning and the rich, subjective, and expressive qualities to emerge in interaction.

Aside from replacing human body parts, 3D printers can also be used to repair practically anything that has never been repaired. Figure 1 shows the general applications of AM field in repair and restoration [11]. This review article gives a general overview of AM application in repairing and restoring components of similar and diverse materials in many fields. Further study in this field of AM is required so that its limitations may be addressed and the full potential of this manufacturing technology can be reached [12]. This review article is based on the most recent advances in AM from 2015 until 2021.

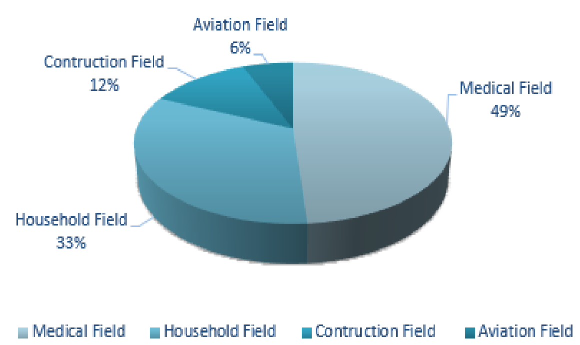


Figure 1 General application of 3D printing field in repair and restoration

2.0 METHODOLOGY

Systematic reviews consist of two major features namely transparency, which allows other researchers to replicate it, and comprehensiveness, which discovers, evaluates, and creates current studies on a certain issue [13]. In systematic analysis, readers will learn what is familiar about a topic and what is unfamiliar with a subject.

This systematic review was carried out in accordance with the published journals, items for systematic reviews, and meta-analysis criteria. Scopus, the Institute of Electrical and Electronic Engineers' abstract and citation databases, and Elsevier's databases were all consulted during the process. This section discusses the criteria that were used to search 152 conference papers and journal articles, as well as how pre-set criteria for exclusion were applied to eliminate duplicate submissions and papers that were beyond the scope of the review.

Table 1 Systematic Review Criteria

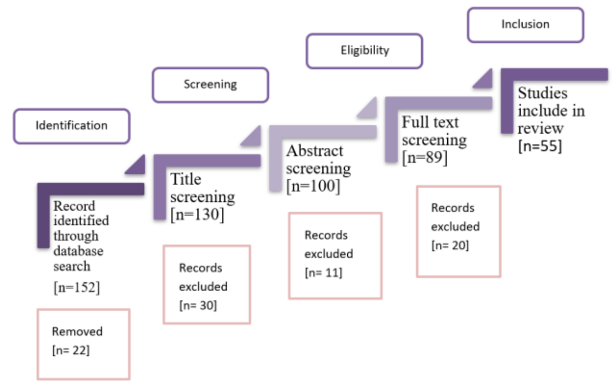
Category	Terminology
AM	3DP, 3D printer, 3-D printer, additive manufacturing, automation in construction, concrete printer, bone printer, in situ printer
Viability	challenge, cost, design, economic, efficient, energy, environment, labour, life cycle assessment, limit, logistic, maintenance, manpower, material, mobility, optimize, productivity, recycle, security, speed, strength, structure, supply, time, transport

A search of the database with a specified search phrase that included seven circumstances related to AM, nine conditions related to engineering, and 28 sentences related to the possibility of the endeavour, as shown in Table 1 was done. The search brought up research papers and journal articles that had the phrase "AM" an engineering term, and a viability term in their title, keywords, or abstract. These terms were present in at least one of the three categories. Because it was important that the search results be as comprehensive as possible, no terms were excluded. To streamline and quicken the process of removing duplicates and screening applicants, the Covidence software was used and a total of 152 papers was added. These documents satisfied all the criteria that were searched for.

Figure 2 shows the flow diagram of the systematic review that summarises how the search results were narrowed. Once again, the Covidence software was used to find and remove 22 duplicate entries before the screening. The authors then developed a three-stage screening process with preset exclusion criteria:

i. Any non-repairable applications such as education, food, and micro-scale
ii. All techniques of non-material extrusion, including selective laser binding jetting, powder bed infusion spraying, and sintering heat.
iii. Recordable materials.

The first screening examined the titles of these articles and removed 30 of them according to predetermined criteria for exclusion. In the second screening, which concentrated on record abstracts, 11 further records were eliminated. Finally, reviewing 89 full-text articles and removing 20 documents left 55 records for synthesis and inclusion.



3.0 CHARACTERIZATION OF LITERATURE AND BIBLIOMETRIC ANALYSIS

This section describes the literature, and the 55 articles included in the systemic review are bibliometrically analyzed. A time-series analysis, to begin, identifies trends in publishing statistics. The top-producing nations in AM repairing are then identified using a geographical analysis. A journal test is conducted to determine the publications most commonly mentioned as well as the journals and conferences most frequently represented.

3.1 Analysis of Time Series

Figure 3 illustrates the evolution of AM repairability research from 2017 to 2021. Between 2015 and 2018, there were very small advances in this field of study. Before 2018, up to three pieces were published in any given year, except for 2017, which saw the publication of five articles. There was a substantial increase in research on AM repair applications, with the corpus of works gradually increasing over the years that followed. Printing applications, methods, labour evaluation, cost, efficiency, environmental impact, logistics, structural design, and even aeronautical application have benefited from research.

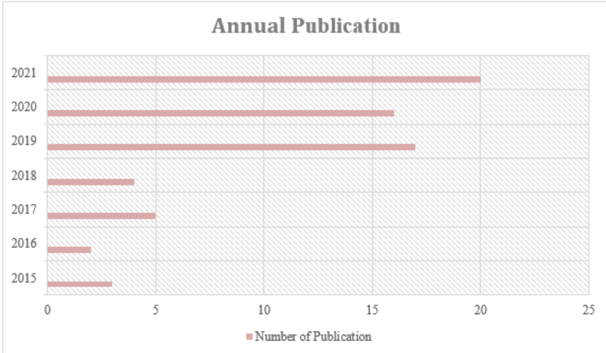


Figure 3 Annual Publication from 2015 to 2021

3.2 Analysis of Location

Figures 4 and 5 depict the nations with the most publications and citations in the area. Aside from the United States, the following nations have published at least three papers: the United Kingdom 3 papers, Korea 3 papers, Australia 3 papers, France 4 papers, Germany 7 papers, Turkey 3 papers, and Iran 3 papers. While China generated the most overall publications in 2019, the United States produced the highest number of citations which is 19 papers. This systematic review involves 55 publications from 22 different nations.

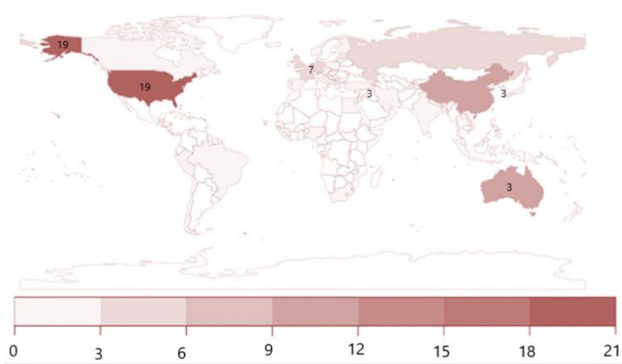


Figure 4 Total publication by country

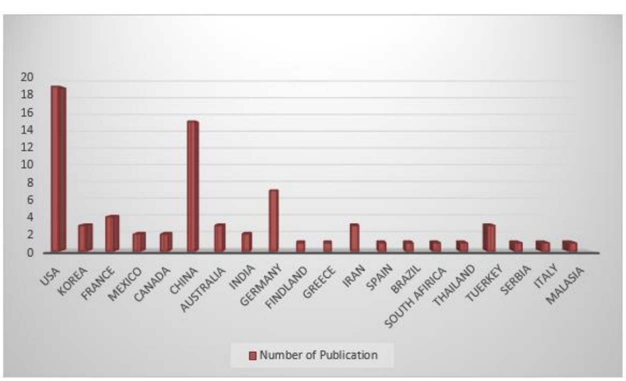


Figure 5 Most cited countries

4.0 RESULTS

4.1 Repair on 3D Printed Parts

Repairing 3D printed items entails replacing broken 3D printed parts. The first study examined 3D-printed part repairability and dealt with the problem of repairing a 3D-printed denture base. Shear bond strength changes after surface treatment and artificial ageing, published in the journal of the mechanical behaviour of biomedical materials [14]. This study investigated 3D-printed denture base material repairability. Surface treatments and artificial ageing affected shear bond strength (SBS) in this investigation. SBS is a measure of how well two materials can withstand shear forces [14]. The combination of digital light processing technology (Rapid Shape D30II) with AM denture foundation material resulted in the manufacture of 224 unique denture foundations (FREEPRINT denture). After surface treatment and artificial ageing, SBS and failure mechanisms were examined and failure mechanisms were examined after surface treatment and artificial ageing to evaluate if the damage might be restored [15]. After that, half of the samples were aged by 5,000 thermocycles at 5–55°C. The SBS did not substantially differ between non-aged groups (p 0.05) and the failure of cohesive bindings in the denture base material. The aged control and monomer groups were the ones that showed the most adhesive failures at the interface, and their SBS values were significantly lower than the ones that the groups that came before them had (p0.05) [14]. Despite the fact that AM technologies are presently being used to assist in dental treatments, the performance of new dental materials still requires further investigation. This is because the manufacturer did not supply any instructions for repairing the 3D-printed denture.

Following the Saab Trials, the 3D-printed Gripen for combat section explains how AM may be utilized in battlefield damage restoration. The Gripen was outfitted with a new hatch that was 3D printed utilizing AM and a nylon material known as PA2200 [17]. Rather than inside 3D-printed components, an external 3D-printed item was flown on a Gripen. Saab completed the experiment. The initial post-flight assessment of the hatch was extremely favourable, revealing that no visible structural alterations had occurred because of the flight.

This study proposes a parallel machine scheduling mathematical approach to optimise 3D printer weapon part production. Many weapons were lost in battle. Complete, medium, or minor weapon damage is categorised. Small weapon destruction can be reused immediately after repair by replacing a broken or lost portion. Troops continually move across the battlefield, making it nearly hard to carry thousands of weapon parts [17]. A 3D printer can be carried to fix the minor destruction of a weapon or unit and used to make parts in the field. This paper presents a scheduling mechanism to create parts quickly after each combat. Parallel 3D printers can make various kinds of parts. 3D printers can make a whole product or two subparts for each part, but making subparts separately increases the workload for that portion because of the attachment for assembly [17]. Thus, making subparts separately takes longer than creating the finished product. Research shows that subpart-split manufacturing for weapon parts can shorten 3D printer production schedules.

This paper focuses on how 3D printing technology can be used for national security. Soldier pays much attention to the supply and upkeep of rifles and many other types of weapons because rifles are the most basic weaponry for the rank and file. Every soldier in a modern army is taught how to take apart and assemble a gun. Nevertheless, a broken gun still has to be taken to the nearest unit that knows how to fix it, which adds a logistical problem to an already busy fighting unit. Having to carry a lot of spare parts to fix rifles could slow down the battle unit [18]. So, in this study, the researcher came up with an Integer Programming model and looked at how well it worked to give affordable 3D printing to combat units to make the process of fixing rifles easier. Researchers performed a computational experiment on the problem. The volume was calculated using the volume of parts for the accurate K2 rifle. According to the degree of loss and fracture, losses and fractures were considered 1%, 2%, and 5% for each component. Assuming the inventory is kept proportionately to the projected losses [18]. There is no safety stock. In addition, the number of soldiers was computed using a 2400-man infantry unit. They constructed ten data sets with varying probabilities to examine the impact on the actual battlefield. Control can be centralised when 3D printers are used, and raw materials can be used more efficiently. In the end, we show how a 3D printer could help a fighting team come up with more creative and effective ways to fight.

4.2 Repair Parts using 3D Printer

Repairing parts with a 3D printer typically entails 3D printing extra parts, which also allows for the repair of products that were not designed to be fixed.

Spall damage restoration utilizing AM technology has detailed information on an innovative approach to treating spall damage that uses a 3D printer to cut down on secondary loss [19]. An area of damage is repaired with a 3D concrete patch. A shear force of up to 15.7 MPa can be supported by a three-dimensional concrete patch adhered to a damaged surface. The proposed approach can sustain this load with a minimum of 91% safety. The structural stability of a concrete repair in response to shear stresses could be even higher than 91% due to the friction between the patch and the damaged surface. While utilizing cast-in-place concrete to fix spall damage, traffic control must be limited for at least seven days [19]. With the proposed method, the road can be closed for just 2 of every 24 hours. If the road is closed for an extended period, this repair is unnecessary. The glue used to secure a concrete patch to a damaged façade determines the patch's long-term structural integrity.

One study demonstrating the promise of using additional material printing as a novel technology for fixing concrete substrates is a 3D printed temperature-detecting fix for substantial buildings [20]. Sending multipurpose supplies within a structural design context is one obvious way to ease the burden on the field [20]. In this work, researchers employed 3D printed adhesive patches with 24 MPa compressive strength, 0.6 MPa glue strength, 0.1°C temperature detection accuracy, and 0.3°C long-term temperature repeatability. An electric suppress heater calcined the kaolin for 2 hours at 800 degrees Fahrenheit [21]. Calcined earth was given time to cool in the heater before being removed and stored in permanent bins. The printed patch adhered to the concrete with 0.6 MPa of force. Due to severe drying shrinkage and limitations in the AM technology, the bond strength achieved was lower than that of a typical geopolymer fix [21].

Additionally, emphasis on shape memory and accurate in situ and self-healing characteristics aims to enhance 3D printability by providing detailed self-healing and directed shape memory (SM) properties using the spatial properties of 3D objects and the convenience of light control, PDAPUs may perform targeted shape restoration [22]. By employing a near-infrared (NIR) laser, the thermoreversible shape-memory polyurethanes (PDAPUs') can be precisely activated for in-situ self-healing without altering their native 3D architectures. Many printed components with 3D permanent shapes could generate shape memories with the induction of light by integrating the shape-memory property with the printability of the PDADU10 [22]. Long-term use often causes degradation and unexpected damage, thus there is a critical need for enhanced reliability and resource utilisation efficiency in 3D printed SM components.

Following that, the researcher aims to investigate the benefits and drawbacks of 3D printing by evaluating human participation in repair activity [23]. The researcher was involved in investigating product repairing activities, which lead to characterised the physicalising of theoretical notions. Several items that were damaged were inspected. Specific repair techniques were then designed with the study's objective in mind [23]. Rather than buying a new product, it may be more appropriate and cost-effective to 3D print a spare component for it. Creating 3D CAD models involves the development of abilities, knowledge, expertise, and precision.

Then, spare parts classification for suitability aimed to create a spare parts categorisation for 3D printing. The classification aims to help businesses make better decisions by displaying the sorts of replacement parts compatible with the technology [24]. Furthermore, an article to determine whether AM is feasible for delivering spare parts to extend product lifespans was published. This article also investigates print-to-repair instances that use private low-cost desktop AM and print-to services [24]. Printing replacement components is an example of a step toward this transition. Personal low-cost desktop computers may rapidly and efficiently create functioning replacements.

This study uses AM to fix partially broken components without requiring specialised technical help. The framework comprises a parts library with AM information, a search engine for autonomously locating broken parts without component expertise, and a shape-differentiating module for evaluating restored components based on damage detection and error measurement [18]. The suggested maintenance framework's support system offers the necessary information for restoring partially damaged pieces. By repairing broken components rather than remanufacturing them, the proposed framework requires less time and money for maintenance [25]. Various registration procedures could be researched to improve the precision of damage recognition and error evaluation.

A new generational notion is the use of AM for domestic applications. The purpose of the study was to develop personalised goods based on the demands of the consumer and to apply AM for the creation and maintenance of household items. Flash Forge's Creator Pro 3D printer offers the FDM or Fused Filament Fabrication (FFF) AM technique [26]. This method utilises thermoplastic polymers including Polylactic Acid (PLA), Polycarbonates, and acrylonitrile butadiene styrene (ABS). May produce customised products depending on consumer requirements. Fabrication is reliant on design.

The goal of this was to identify how spare components might be constructed from photographs and manufactured using a conventional or 3D printer [27]. A composition from motion method generates a limited quantity of images that display the spare component from each aspect and may be captured with a digital camera. After determining the size of the real components with a simple user interface, the meshed virtual model may be suitably scaled. Without printing the replica, the full reconstruction procedure on the tablet takes about 4 hours [27]. The tablet's computational power is a bottleneck for executing the Poisson algorithm and the Visuals FM. No UI metaphors for touch devices allow the user to increase the density of the point cloud by highlighting object symmetries.

These reviews by [28] intended to explain the primary characteristics and applications of scaffold design for bone regeneration. Including polymers, ceramics, metals, and composites, material applications and issues for bone regeneration. Diverse biomaterials and fabrication techniques for patient-specific bioactive scaffolds with controlled microstructures for bridging complex bone lesions have evolved [28]. The fabrication of 3D bio-printed scaffolds has been a promising solution with several advantages, including regulated porosity and design, higher biological activity, and enhanced mechanical properties.

Extensive fractures can be treated with state-of-the-art robotic in-situ 3D bioprinting. This study aimed to publish a paper in the journal of advanced research describing the successful treatment of long segmental bone lesions in a pig model using in situ 3D bio-printing using a robotic manipulator 3D printer [29]. Current 3D bio-printing techniques involve growing cells on a scaffold made with additive manufacturing technology and altering chemicals to grow mature tissue in vitro before implantation. Researchers increased printing precision to 0.5 mm using a D-H kinematic model and carefully adjusted bio-ink gelation under physiological conditions to get the perfect mechanical characteristics for bone regeneration [29]. Direct injury repair in situ 3D bioprinting technology has many obstacles, including biomaterial synthesis, scaffold building with defect-like geometries, and 3D bio-printer development. Faster healing and fewer complications after surgery are two benefits of using in-situ 3D bioprinting technology rather than conventional methods.

In situ repair of bone and cartilage defects using 3D scanning and AM scientific reports to describe the use of 3D scanning and AM in tandem to repair bone and cartilage abnormalities [30]. Three types of defect models were developed to simulate three orthopaedic diseases:

- ❖ Large long bone segmental defects
- ❖ A fracture of the femoral condyle that is freeform in nature
- ❖ Chondral lesion of grade IV according to the international cartilage repair society

In order to create the faults, the Boolean operation was used, and once that was done, the target geometries were fed into a 3D bioprinter. Using 3D bioprinting allowed for the successful correction of all three defects [31]. To mend bone and cartilage, two distinct types of hydrogels were used. This method offered a novel approach to treating open wounds that were found in the skeletal system.

An article on the AM of hydrogel scaffolds for potential use in the future application of photothermal treatment for breast cancer and tissue repair [32]. The treatment for breast cancer and the filling of the hollow are intended to bring about the healing of the tissue. Inks for printing were made out of easily available materials (dopamine-modified alginate and PDA), both of which have a good level of biocompatibility [32]. Using the use of 3D printing, a bifunctional dopamine-modified alginate and polydopamine (PDA) scaffold was developed. The tight PDA gave the Alg-PDA scaffold excellent photothermal activity, destroying cancer cells and preventing local breast cancer recurrence. Only one kind of that species was utilised.

Moreover, dual crosslinked oxidised alginate-gelatin hydrogels containing human nasoseptal chondrocytes will be 3D printed and characterised for use in cartilage restoration techniques. Grid-like 3D-printed patterns for cartilage tissue engineering were published in engineering and materials science [33]. Before 3D printing, ADA-GEL was injected with human nasoseptal chondrocytes. At 7 and 14 days, we tested the cells for viability, proliferation, and metabolic activity. Enzymatic and ionic crosslinking with microbial transglutaminase (mTG) and divalent ions (CaCl2) made 3D-printed products durable [33]. Increases in ADA-GEL concentration were associated with a corresponding increase in the rigidity of ADA-GEL- and ADA-GEL+ structures.

Following that, a systematic review on applications of AM in the craniofacial bone repair which was aimed to blend data from existing human and creature research on using AM for bone fix and recovery in the craniofacial region [34]. Due to strict incorporation and rejection guidelines, a thorough investigation of all significant clinical preliminary studies and case studies was conducted. The rules were met by 43 distributions (6 human and 37 creature research) [34]. 81 people with craniofacial bone irregularities were remembered for the human preliminaries. The regularly embedded platforms were titanium or hydroxyapatite. This systematic audit only evaluates 3D printed platforms in living individuals. Human and animal research can help understand these methods. The goal was to merge human and animal AM studies on craniofacial bone repair and healing. In light of determined consideration and prohibition models, an exhaustive hunt of all pertinent clinical preliminaries and case series was led. The measures were met by 43 distributions (6 human and 37 creature research). Altogether, 81 people with craniofacial bone anomalies were remembered for the human preliminaries [35]. The regularly embedded platforms were titanium or hydroxyapatite. The current systematic audit incorporates just in-vivo studies to evaluate the utilisation of 3D printed frameworks in live people [35]. Human and creature examination can be consolidated to comprehend these methods better.

Recent advances in 3D-Printed polylactic acid and its applications in bone repair and the goal of advanced engineering materials was to create anatomical models for surgical purposes, training, education, and patient-specific instruments (PSIs) for aiding surgery and complicated bespoke implants or organs [36]. These models can also be used in education. Biomaterials that are SLS 3D-Printed and Based on PLA 2. The in vitro performance, clinical efficacy, and practicability of FDM-printed PLA scaffolds are unknown. This is the study's current restriction [36]. 3D printing technology has enabled new approaches to enhance biological materials for orthopaedic applications. The innovative bioactive substance can be put to use in clinical settings to replace dead or damaged bone tissue with artificial scaffolding that also possesses bioactive properties.

In addition, the use of a tissue-engineered bone was produced in three dimensions for canine mandibular abnormalities [37] wanted to fix the bone tissue abnormalities found in the experimental canines' oral and maxillofacial (OMF) regions. Nine male Beagle dogs' bone marrow stromal cells (BM found in the experimental canines' oral and maxillofacial (OMF) regions) were taken out and cultivated in vitro for osteogenic differentiation [30]. A high-precision ProJet1200 printer searched the OMF region for a 3D-printed surgical guide plate and mould made of implant materials and sintered at 1250°C. The second generation of the experiment cultured osteogenic BMSCs (P2) [38]. To create the nanoporous hydroxyapatite implant, an AM mould was used. This mould had a porous white structure and a rough surface. The rate of decay is inconsistent, the body is too rigid, and there is not enough give.

Trends in 3D bioprinting for oesophagal tissue repair and restoration were published in the journal biomaterial to thoroughly review current advancements in tissue engineering for oesophagal repair, emphasising 3D bioprinting techniques in ETE. Repairing the damaged oesophagus is being investigated as a potential treatment option [38]. Existing biomanufacturing processes and bio-ink properties include cell-loaded, cell aggregates in hydrogels or cell-seeded micro-carriers, cell-free, viscous fluids, and (synthetic or natural) polymers that provide mechanical support to the designed scaffold. These characteristics are representative of a cutting-edge research programme aimed at incorporating dynamics [39]. The artificial oesophagus includes the following features such as a hollow, muscular tube that carries food and liquid from your throat to your stomach.

An overview of the hard tissue engineering technique of controlled release to replicate the intricate organisation of genuine tissues is provided here, along with nanotechnology and scaffold implantation to efficiently restore damaged organs [40]. The most current technological developments, experiments, and future prospects of hard tissue engineering are discussed in this article. An intra-porous cylinder is used to filter a polymeric solution [40]. The results demonstrated that the 3D-printed scaffold increased cell adhesion, growth, and proliferation. This was based on the fact that molecules were present through the holes for an extended period of time. Brittle organs and tissues such as bone, teeth, and cartilage are involved [41]. The lone pair of electrons on the amino group of the -PL attack the epoxy group on the GMA and undergo nucleophilic addition to form secondary amines and hydroxyl groups.

An antibacterial antioxidant carboxymethyl cellulose/beta-polylysine hydrogel that was created using a 3D printer aided in the healing of skin wounds [43]. They developed novel printable bionic hydrogels with antibacterial and antioxidant properties, which can effectively overcome the hurdle by reducing inflammation and accelerating wound healing [43]. Using a 3D printer and ultraviolet (UV) light polymerisation, the CMC/PL (CP) hydrogels were manufactured by combining glycidyl methacrylate (GMA) modified carboxymethyl cellulose (CMC) and polylysine (PL). Ring-opening reactions with GMA occur when the CMC and PL are exposed to only slightly acidic conditions [44]. Cyclopropane on GMA can open the ring under acidic circumstances. This medicine treated irregular wounds.

This study focused on reducing unfavourable immune responses and enhancing tissue integration by permanently converting macrophages to the M2 pro-healing phenotype using 3D-printed silicone implants with immunomodulatory hydrogels [45]. A rat model was utilised to repair a tracheal abnormality using 3D-printed silicone implants [45]. A novel cytokine cocktail containing interleukin-10 and prostaglandin-E2. This cytokine kept up with low degrees of support of inflammatory cytokine (TNF- and IL-6) creation and advanced the discharge of IL-10 just as the upregulation of M2 macrophage-communicated multifunctional rummaging and arranging receptor stabilising-1 [46]. The covering stayed stable on the silicone inserts for over fourteen days, and the mixed drink parts were delivered in a directed way for about fourteen days. Just spotlights on the tracheal region.

Components with biological activity bone healing have been found to be expedited and improved using a 3D printed scaffold with an interior vascular network modelled after a lotus seedpod [47]. Hydrogel microspheres containing deferoxamine (DFO) liposomes were manufactured as "lotus seeds" using microfluidic technology, and then expertly connected with a biomimetic "lotus" biological structure three-dimensional (3D) printed bio ceramic scaffold that can generate blood vessels from within. Improved expression of vascularization and the osteogenic proteins Hif1-, CD31, OPN, and OCN were observed in a rat femoral lesion model treated with a composite scaffold [48]. Blood vessel growth within the scaffold might be encouraged in this way. In this case, a rat with a femoral malformation serves as the subject of the investigation.

An in vitro investigation of the effects of several surface treatments on the roughness and flexural strength of a 3D-printed denture base that has been repaired. Specifically, the journal by [49] will analyze how different surface treatments affect the surface roughness and flexural strength of a repaired 3D-printed denture base [49]. 120 Acrylic resin bar specimens made using a 3D printer were divided into six categories. Each specimen was sectioned, and then the surface roughness was measured with a profilometer before being repaired with auto-polymerizing acrylic resin and thermocycling [49]. Repair of denture bases was lessened by filling gaps larger than 1 mm, but all surface-treated groups showed significantly higher flexural strength.

4.3 Technology

This article was reviewed for technology using 3D pens to enhance and rework 3d-printed parts. This paper shows a 3D pen, which may be used to repair 3D-printed components by adding material, "welding" ABS or PLA plastic pieces, customising and adorning 3D printed items, or creating free-hand 3D plastic creations [50]. Three different manufacturers' 3D pens are used. Two laboratory activities utilise 3D pens for welding plastic and customising 3D-printed items [50]. If not handled with prudence, this device has the potential to cause injury. The use of 3D pens in AM practices came next [51]. This presentation will demonstrate the usage of AM Pens in various activities and report on the benefits and downsides of 3D Pen exercises identified via recent research. A 3D Pen enables anyone to draw in the air [52]. Once completed, it is clear that this method has the potential to be an incredible tool for wireframing future goods, particularly in the small-scale world of different useable things in everyday life and even mending components.

Figure 6 Butterfly made with a 3D Pen [52]

Furthermore, research conducted has designed a hydrophobic pattern in paper substrates to develop paper-based analytical instruments (PADs) using the suggested pen-on-paper technique [53]. A commercially available plastic welding kit was utilised, comprising an acrylate-based resin placed on the paper and then cured with a UV light. All the substances employed in this experiment were of analytical quality, including acetonitrile, ethanol, methanol, and acetone. Liquid plastic resin demonstrated good resistance to frequently used organic solvents and surfactant solutions, in addition to its suitability for use in the manufacture of flow and paper electrochemical devices [54]. The fabrication protocol is simple and accessible to any laboratory.

The following was an article on cartilage regeneration using in-situ portable 3D bioprinting has compared the Bio pen's early cartilage regeneration results to those of other therapies and its ability to cure a full-thickness chondral injury in a large animal model [55]. On the weight-bearing surface of both the lateral and medial condyles of the six sheep's femurs, a critical-sized, entire-thickness chondral defect was produced. The in vivo period lasted for 8 weeks, and all animals survived. Each of the animals improved considerably after undergoing bilateral stifle operations [55]. Using the Bio pen during surgery caused the author no peri-operative issues.

5.0 CONCLUSION

In conclusion, this overview of research into previous studies examines the potential and limitations of 3D printers in the realm of product repair and restoration. The findings were beneficial in understanding the potential of AM technologies for mending physically damaged items. Using an AM to create spare parts offers a lot of promise for refurbishing and restoring items. Furthermore, these components might be developed to customise or improve the product's design and support the remanufacturing process. Some of the difficulties discovered during the review process were the knowledge, skills, and time required and the precision required to develop the CAD models. The most challenging stage was creating a 3D-printable functional component. The process demonstrates how difficult it is to determine which parts will be suitable for 3D printing. It is likely due to the strictness of part requirements rather than the type of requirements. A future study will look into this. Repairing a product is the most environmentally friendly option. Through repair work, people can forge meaningful connections with the objects in their lives, and the potential of AM and other technologies can help facilitate this and support environmental sustainability.

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