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A Systematic Literature Review On The Application of Additive Manufacturing in Repairing Parts

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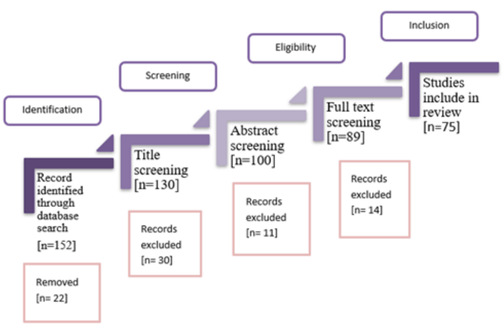
Graphical abstract



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

Charles Hull invented the stereolithography machine, one of the first 3D printers, in 1986. Soon after, stereolithography and numerous other significant patents formed the fundamental expertise of Hull's 3D Systems. Scott Crump created fused deposition modeling (FDM), another AM method a few years later in 1988 [1]. FDM was the cornerstone for the firm he co-founded with his wife, Lisa Crump, Stratasys, a year later.

Digital fabrication, also known as 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 [1]. It is a multidisciplinary strategy that combines materials science, structural engineering, mechanical engineering, and software engineering.

Currently, 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, there is a wide range of 3D printers available [2]. 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 [1]. The proliferation of the maker movement contributed to a rise in the number of people interested in 3D printers [2].

Because of the quick development of technology, businesses are now able to offer AM services as well as affordable desktop 3D printers. Before the advent of the concept of disposability and the subsequent industrial revolution, the majority of people lived their lives as producers. We now buy things that people used to manufacture, while they used to fix the things that we toss away [3]. Our relationship with material things has undergone profound change and is today fraught with difficulties. 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.

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 [4]. Engineers and academicians may use a 3D printer in nearly every sector.

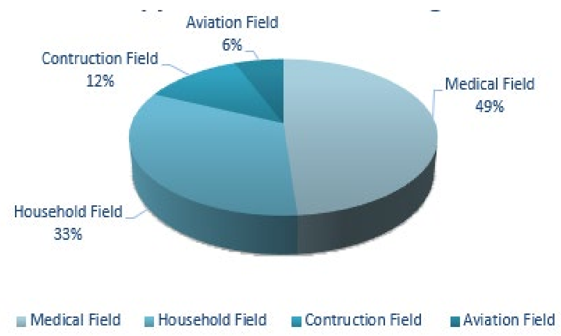


Figure 1: Application of 3D printing

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. This review article gives a general overview of AM application in repairing and restoration of components made 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 [52]. This review article is based on the most recent advances in AM during the previous seven years.

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 [53]. In systematic analysis, readers will learn what is familiar about a topic and what is unfamiliar with a subject.

Table 1: Systematic Review Criteria

Category	Terminology
AM	3DP, 3D printer, 3-D printer, additive manufacturing, 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

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.

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.

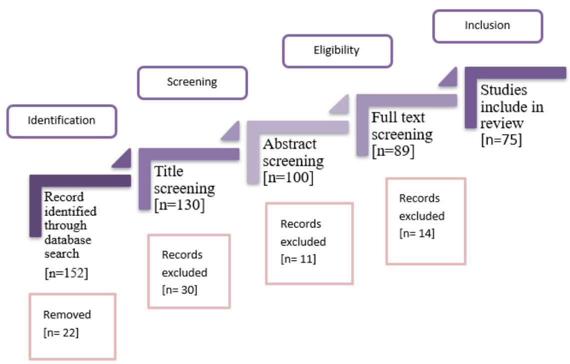


Figure 2: The flow diagram of the systematic review

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 14 documents left 75 records for synthesis and inclusion.

3.0 CHARACTERIZATION OF LITERATURE AND BIBLIOMETRIC ANALYSIS

This section describes the literature, and the 75 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 75 publications from 22 different nations.

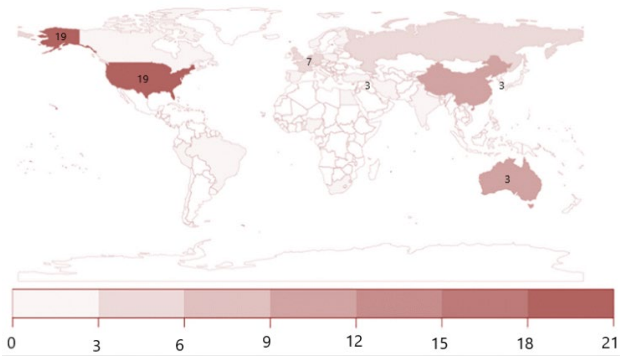


Figure 4: Total publication by country

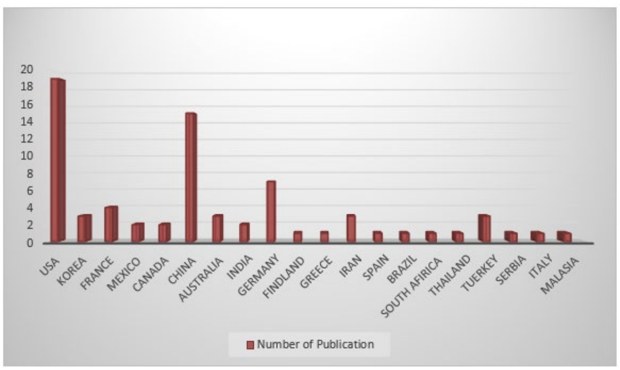


Figure 5: Most cited countries

4.0 RESULTS

4.1 Repair on 3D Printed Parts

The first study examined 3D-printed part repairability and dealt with the problem of repairing a 3D-printed denture base. Shear bond strength (SBS) changes after surface treatment and artificial ageing [5]. SBS is a measure of how well two materials can withstand shear forces. This study investigated 3D-printed denture base material repairability. Surface treatments and artificial ageing affected SBS. 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 to evaluate if the damage might be restored. 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) [5]. 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 due to the fact that 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 [6]. Rather than inside 3D-printed components, an external 3D-printed item was flown on a Gripen and 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.

The work published by Khosravani & Reinicke, 2021 tries to probe the effect of construction faults on the mechanical performance and fracture behaviour of 3D-printed components by comparing the performance of both intact and defective specimens. Polymeric samples were printed in two separate raster directions [7]. Extensive thermal ageing testing was also performed on the 3D-printed samples. To determine how thermal ageing impacts part mechanics, elastic tests were performed on aged and unaged test coupons. This study examines how reliable adding pieces is. Thermal ageing doesn't change how the specimens look on the outside, but it does make them less strong [7]. The experimental data showed that the examined specimens' technical behaviour was modified and their failure loads were decreased due to thermal ageing. The results of the tests indicate that the tested specimens' mechanical properties changed as a result of thermal ageing.

Additionally, X-ray computed tomography was used in a porosity study of extrusion-based 3D printed concrete in order to observe and measure the porosity sizes, pores, shapes, and allocations [8]. Minimizing the work required to remove and examine samples from freshly 3D-produced filaments of concrete is accomplished with the aid of moulds made from plastic manufactured using a 3D printer. 3D printed and cast without-compaction concrete mixtures are compared in the study. These minute pores may meaningfully contribute to concrete's mechanical and resilience performance, so their diameter is kept constant at 20mm while their height varies between four layers (40mm), two layers (20mm), and a single filament layer (10mm), both intra and interlayer and in comparison to cast concrete [8].

4.2 Repair Parts using 3D Printer.

Spall damage restoration utilising AM technology, has detailed information on an innovative approach to treating spall damage that uses a 3D printer to cut down on secondary loss [10]. An area of damage is repaired with a 3D concrete patch. While utilising cast-in-place concrete to fix spall damage, traffic control must be limited for at least seven days [10]. 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 of time, this form of repair is not necessary. 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 [11]. Sending multipurpose supplies within a structural design context is one obvious way to ease the burden on the field [11]. In this work, researchers employed 3D printed adhesive patches with 24MPa compressive strength, 0.6MPa 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 [12]. 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 0.6MPa 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 [12].

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 [15]. 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 [15]. 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, researcher aims to investigate the benefits and drawbacks of 3D printing by evaluating human participation in repair activity [16]. The research 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 [16]. Rather than buying a new product, it may be more appropriate and cost-effective to 3D print a spare component. In addition, creating 3D CAD models involves the development of abilities, knowledge, expertise, and precision. Then, spare parts classification for suitability aimed to create 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.

Furthermore, an article to determine whether AM is feasible for delivering spare parts to extend product lifespans was published [17]. This article also investigates print-to-repair instances that use private low-cost desktop AM and print-to services. Printing replacement components is an example of a step toward this transition. Personal low-cost desktop computers may rapidly and efficiently create functioning replacements.

Kim et al. 2019, studied the use of 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]. They suggested that 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 [18]. 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 [19]. It may produce customised products depending on consumer requirements and the fabrication is reliant on design required by the consumer.

Schoning & Heidemann, 2016 identify how spare components might be constructed from photographs and manufactured using a conventional or 3D printer [20]. 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 [20]. 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.

Reviews by Wang et al. 2021, intended to explain the primary characteristics and applications of scaffold design for bone regeneration including materials such as 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 [21]. 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. A study 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 [22]. 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 [22]. 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 to repair bone and cartilage abnormalities has also been reported [23]. 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 [23]. 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 by Luo et al. 2019, on the AM of hydrogel scaffolds for potential use in the future application of photothermal treatment for breast cancer and tissue repair [25]. 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 [25]. Using 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 [25].

Moreover, dual crosslinked oxidised alginate-gelatin hydrogels containing human nasoseptal chondrocytes was 3D printed and characterised for use in cartilage restoration techniques. Grid-like 3D-printed patterns for cartilage tissue engineering were also published [26]. Before 3D printing, ADA-GEL was injected with human nasoseptal chondrocytes. At 7 and 14 days, the cells were tested for viability, proliferation, and metabolic activity. Enzymatic and ionic crosslinking with microbial transglutaminase (mTG) and divalent ions (CaCl2) made 3D-printed products durable [51]. 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 by Maroulakos et al. 2019, on applications of AM in the craniofacial bone repair which aimed to blend data from existing human and creature using AM for bone fix and recovery in the craniofacial region [26]. 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) [27]. 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 current systematic audit incorporates just in-vivo studies to evaluate the utilisation of 3D printed frameworks in live people [28]. 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 [29]. These models can also be used in education. Biomaterials that are laser sintered 3D-parts and based on PLA. The in vitro performance, clinical efficacy, and practicability of FDM-printed PLA scaffolds are unknown. 3D printing technology has enabled new approaches to enhance biological materials for orthopaedic applications [29]. 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 to fix the bone tissue abnormalities found in the experimental canines' oral and maxillofacial (OMF) regions was conducted [30]. Nine male Beagle dogs' bone marrow stromal cells were taken 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 [31]. The second generation of the experiment cultured osteogenic BMSCs (P2). 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 [32]. 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 [33]. 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 along with nanotechnology and scaffold implantation to efficiently restore damaged organs [34]. 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 [34]. 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 [35]. The lone pair of electrons on the amino group of the polylysine (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 [36]. They developed novel printable bionic hydrogels with antibacterial and antioxidant properties, which can effectively overcome the hurdle by reducing inflammation and accelerating wound healing [36]. 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 [37]. Cyclopropane on GMA can open the ring under acidic circumstances. This medicine treated irregular wounds.

Barthes et al. 2021, 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 [38]. A rat model was utilised to repair a tracheal abnormality using 3D-printed silicone implants [38]. 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 [39]. 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.

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 [40]. Hydrogel microspheres containing deferoxamine (DFO) liposomes were manufactured as "lotus seeds" using microfluidic technology, and then connected with a biomimetic "lotus" biological 3D printed structure of bioceramic scaffold that can generate blood vessels from within. In this case, a rat with a femoral malformation serves as the subject of the investigation. 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 [41]. Blood vessel growth within the scaffold might be encouraged in this way.

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 was conducted. Neshandar & Rahimabadi, 2021 analysed how different surface treatments affect the surface roughness and flexural strength of a repaired 3D-printed denture base [42]. 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 [43]. 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

Jaksic, 2015 used 3D pens to enhance and rework 3d-printed parts. This article 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 [44]. Three different manufacturers' 3D pens were used. Two laboratory activities utilise 3D pens for welding plastic and customising 3D-printed items [44]. If not handled with prudence, this device has the potential to cause injury. This article 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 [46]. 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.

Furthermore, research conducted by Aguilar & Petroni, 2020 has designed a hydrophobic pattern in paper substrates to develop paper-based analytical instruments (PADs) using the suggested pen-on-paper technique [47]. 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 [48]. The fabrication protocol is simple and accessible to any laboratory.

Finally, an article on cartilage regeneration using in-situ portable 3D bio printing was reviewed. Di Bella & Duchi, 2017 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 [49]. 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 [49]. 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. 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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