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Review

Additive Manufacturing Technologies and Their Applications in Dentistry: A Systematic Literature Review

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Abstract

Additive manufacturing (AM) has emerged as a transformative technology in dentistry, enabling the production of patient-specific dental applications with reduced costs and fabrication times. Despite the growth of applications, a consolidated understanding of current 3D printing technologies, materials, and performance in dental settings remains fragmented. Here, we perform a Systematic Literature Review (SLR) using the PRISMA protocol, retrieving 19 closely related primary studies. The evidence is synthesized across three axes: application domain, AM technology, and critical quality parameters. Dental restorations, prosthetics, crowns, and implants are the most common applications, while fused deposition modeling, stereolithography, digital light processing, selective laser sintering, and laser-directed energy deposition are the most used technologies. AM materials include polymers, metals, and emerging biomaterials. Key quality determinants include dimensional accuracy, wear and corrosion resistance, and photosensitivity. Notably, biocompatibility and cytotoxicity remain underexplored yet critical factors for ensuring long-term clinical safety. The evidence also suggests a lack of in vivo studies, insufficient tribological and microbiological testing, including limited data degradation pathways of AM materials under oral conditions. Understanding that there are disconnects between the realization of the clinical and the economic benefits of 3D printing in dentistry, future research requires standardized testing frameworks and long-term biocompatibility validation.

Keywords: additive manufacturing; 3D printing technology; dentistry; dental application; dental prosthetics; dental implant; dental crown; dental restoration

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1. Introduction

The use of additive technologies or 3D printing involves modeling and prototyping, increasingly, of finished products [1,2], by adding materials layer by layer to obtain products of the desired shape, characteristics, and features [3]. Over the past two decades, the use of additive technologies has expanded to all branches of industry and non-industry [4], while their application in medicine has recorded significant growth in recent years [5]. A potential problem with the application of additive technologies in medicine is the impact of the materials used and their repercussions on human health [6]. In dental applications, methods such as manual production or computer numerical control (CNC) machining of prostheses and implants are used [7–9]. Given that no two people have identical dental images, the personalization of finished products in dental applications is essential, so the time required to produce such products, and their quality are key factors for the introduction of advanced technologies in dental prosthetics [10,11]. The application of 3D printing technology enables faster, but equally precise, production of prostheses and implants, as well as simple design changes and the production of products with very complex geometry [12,13], while the expansion of these technologies will make production prices more affordable.

According to Ref. [14], the application and choice of 3D printing technology in dentistry directly depend on the type of material used. Thus, for crowns or bridges made of metal alloys or ceramics, selective laser sintering (SLS), selective laser melting (SLM), and direct metal laser sintering (DMLS) technologies are frequently used, while fused filament fabrication (FFF) or fused deposition modeling (FDM) technologies are most often used for the production of implants and prostheses made of polymer-based composites. However, recently, new materials that need to meet numerous demands about characteristics, such as mechanical and aesthetic, as well as antimicrobial properties, have been increasingly investigated [15]. To identify research gaps and formulate Research Questions (RQs), the following paragraph presents an analysis of review papers.

A literature review of the main types of additive manufacturing (AM) technologies with a focus on mechanical characterization is presented by Nezir et al. [16]; the authors compared the advantages and disadvantages of the analyzed materials from the aspect of applications in orthopedics, dentistry, prosthetics, etc. A literature review with a focus on the cytotoxicity of acrylic resin materials used in digital light processing (DLP) or stereolithography (SLA) printing technologies in prosthodontic appliances is presented by Arossi et al. [17]; the authors searched the Scopus, Embase, and Ovid MEDLINE databases, concluding that there are no significant differences in the biocompatibility of the available resins or washing solutions. A review of the biomedical applications of titanium alloys, where the properties of titanium and its alloys for orthopedic implants and dental prosthetics are analyzed, is presented by Marin et al. [18]; the authors focused on the specific parameters of titanium alloys compared to other materials, as well as the limitations of titanium alloys in biomedicine. A review of 3D printing of dental prostheses with a focus on current and emerging applications is presented by Rezaie et al. [19]; the authors searched Google Scholar, PubMed, ScienceDirect, Web of Science (WoS), and Scopus databases to analyze the possibilities of using different materials in dentistry, including thermoplastic polymers, ceramics, and metals. The achievements and applications of 4D printing in dentistry, with a focus on shape-changing polymers and composites, are presented by Palanisamy et al. [20]; in addition, the authors discussed the potential benefits for patients as well as the current limitations of the application of this technology in dentistry. A systematic review and meta-analysis of computer-aided technology for fabricating removable partial denture frameworks are presented by Pordeus et al. [21]; the authors used the Cochrane Collaboration criteria and PRISMA Statement when searching and analyzing the literature—as a result, there is a similar fit and esthetic improvement in the comparison of the 3D printed prosthesis with the one made by conventional techniques. The polymeric materials used in 3D printing in dentistry with a focus on biocompatibility testing challenges are presented by Rus et al. [22]; the authors searched Google Scholar, PubMed/MEDLINE, NCBI, WoS, Scopus, and Cochrane Library databases to analyze the types of materials used in 3D printing, product cytotoxicity, polymerization methods, and post-polymerization treatments. A systematic review of the factors affecting accuracy in the AM of interim dental prostheses is presented by Ferreira et al. [23]; the authors used the PRISMA protocol, searching PubMed, WoS, and Embase databases to analyze incorporation and polymerization methods, antimicrobial activity, and the cytotoxicity of organic and inorganic agents added into polymethyl methacrylate (PMMA). Recent advances in the 3D printing of polymers for application in prosthodontics are presented by Dimitrova et al. [24]; the authors searched PubMed, WoS, and Embase databases to evaluate the application of existing 3D printing technologies in prosthetic restorations, as well as the sustainability of conventional methods for manufacturing dental applications. A systematic review of subtractive and additive technologies in fixed dental metal ceramic restoration is presented by Rasheed et al. [25]. The authors searched Google Scholar, PubMed, Science Direct, and Z-library databases to gather data on the computer-aided design and computer-aided manufacturing (CAD/CAM) subtractive and AM technologies. A state-of-the-art review focusing on dental materials applied to 3D and 4D printing technologies is presented by Cai et al. [26]; the authors analyzed metals, ceramics, polymers, and biomaterials, as well as applied printing technologies, while the application of materials for 4D printing, as well as their application in oral clinical medicine, was additionally discussed. A comparative analysis of the mechanical properties and biocompatibility of CAD/CAM polymers and conventional polymers in dental prostheses is presented by Chuchulska et al. [27]; to create a narrative review, the authors searched Embase, PubMed, and WoS databases. A state-of-the-art review of the biocompatibility of PMMA-based dental materials for interim prosthetic restorations is presented by Pituru et al. [28]; the authors analyzed the biocompatibility of materials, i.e., the impact of prostheses formed from PMMA on epithelial cells, fibroblasts, or pulp cells. The application of biomaterial designs to additive modeling, as well as designs for the use of subgroups of biomaterials, such as metal alloys, polymers, and ceramics, is presented by Mirzaali et al. [29]. A literature review within the framework of analyzing dental implants wear mechanisms, materials, and manufacturing processes is presented by Saha et al. [30]; the authors considered the characteristics of metallic materials from various aspects, such as tooth anatomy, wear mechanism, dental implants classification, implant materials, and manufacturing techniques. A literature review from the aspect of analyzing shape memory polymeric materials for biomedical applications is presented by Rokaya et al. [31]; the authors analyzed the type and application of these materials in various fields, such as neuromedicine, dentistry, orthopedics, oncology, etc. A review of polymeric denture base materials is presented by Alqutaibi et al. [32]; the authors searched PubMed, Embase, and Scopus databases to determine the types, applications, properties, and manufacturing technologies of these polymers, while the limitations related to the physical and mechanical properties that affect the application of PMMA in dentistry were given.

Based on the analysis of the available review papers, the following research gaps were determined: (i) more detailed biocompatibility tests are needed before the materials used in 3D printing in dentistry can be used safely, (ii) a lack of clinical studies on the biocompatibility of polymers in terms of their safe use in humans, (iii) a lack of clinical evidence for titanium cytotoxicity, (iv) limited attention is given to the accuracy, surface treatment, and staining of denture base material, (v) a lack of comparative studies directly comparing 3D printing to traditional technology (considering the fit, comfort, and biocompatibility of dental applications), and (vi) a lack of studies assessing the effectiveness of different surface treatments to mitigate potential plaque accumulation.

On the other hand, our research includes the latest use of additive technologies in dentistry from various perspectives over the past 5 years, which is the goal of this systematic review. Depending on the type of material as well as the additive technology used to produce dental applications, the parameters that affect the characteristics of the final product (dental crown, dental prosthesis, etc.) will be determined and discussed in detail. The selected parameters will be compared to determine the most commonly used materials and technologies with the best suitability for dental applications. Limitations that affect the effectiveness of the application of 3D printing in dentistry will also be given. Accordingly, the following RQs were used:

RQ1: What are the most common applications of additive manufacturing in dentistry?

RQ2: Which technologies and materials are most prevalent in dental applications?
RQ3: Which parameters affect the quality and safe usage of 3D-printed dental applications?

The manuscript is structured as follows: the first section presents the motivation and goal of the research, as well as the research gaps in the review papers, based on which the RQs were formed; the second section provides an in-depth explanation of SLR, including the search strategy and extraction of evidence from the selected studies; the third section presents an initial analysis of the articles chosen to determine the used AM technologies, materials, and their parameters; the fourth section provides detailed research results using synthesized content-based data, which includes descriptive and inferential statistics; the fifth section presents a discussion of the results according to the RQs; and the sixth section contains concluding remarks, limitations and implications, as well as future research.

2. A Systematic Literature Review

The SLR performed follows the PRISMA (Preferred Reporting of Items for Systematic Reviews and Meta-Analyses) protocol. This includes a step-by-step description of the search strategy protocol, eligibility criteria, and evidence extraction. The search is performed following the proposed RQs to design search strings using Boolean operators. The search is performed through index bases as follows: WoS, Dimensions, Scopus, PubMed, OpenAlex, and Google Scholar. Figure 1, inspired by the illustration from Ref. [33], displays the complete list of search strings. It should be noted that the syntax was formed after a large number of iterations of strings and keywords, so the syntax with the highest number of hits was adopted. Below, Table 1 shows the results of the initial research.

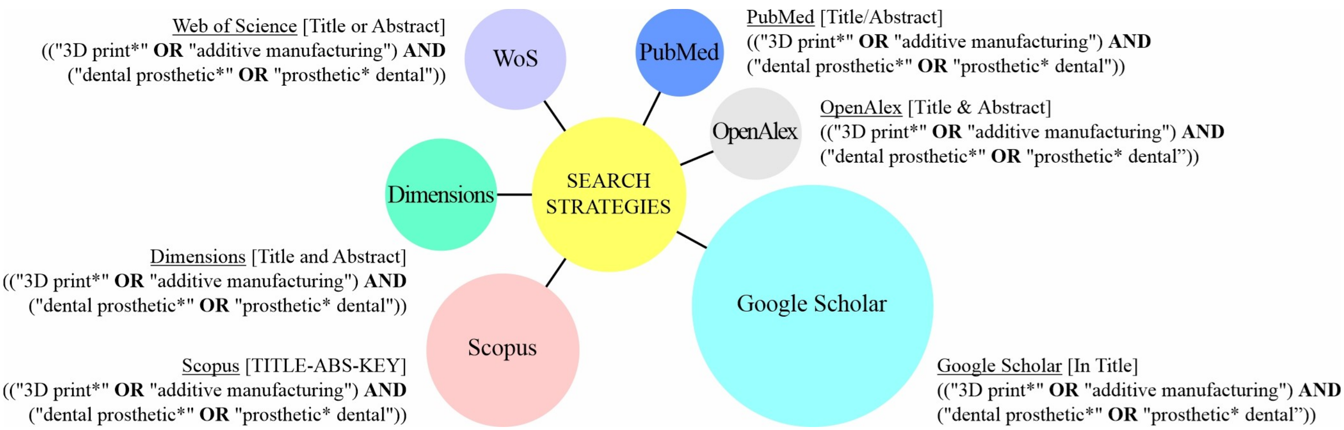

Figure 1. Search strings and index bases used for the synthesis of studies.

The search strategy consists of screening, an eligibility assessment, and an in-depth exhaustive evaluation of studies for reaching a panel consensus. In the screening phase, 338 studies were identified. By applying the Exclusion Criteria–Not English (EC-NENG), studies that were not written in English were excluded (n = 10). Records that were not articles (n = 140) were excluded by Exclusion Criteria–Not Article (EC-NART). Furthermore, the duplicates (n = 69) were manually removed. The remaining 119 studies were deemed relevant and were subjected to an in-depth reading in accordance with the RQs. For this purpose, six additional exclusion criteria (EC) were introduced: EC1—review papers (n = 9), EC2—appearance and surface characteristics or mechanical characteristics of the material tests (n = 58), EC3—monograph (n = 1), EC4—studies on patients (n = 20), EC5—3D modelling and software (n = 6), and EC6—year out of scope [1 January 2020—1 May 2025] (n = 1), while the remaining five studies were not available for download (n = 5). The Inclusion/Exclusion criteria are detailed in Table S1. Finally, nineteen articles (n = 19) are identified as relevant for further analysis. Figure 2 shows the PRISMA flow diagram.

Table 1. Results of the initial search of each database individually.

Database	Language	Article	Review	Conf. Paper	Book	Book Chapter	Letter	Editorial	Patent	PhD Thesis	MSc Thesis	BSc Thesis	Total
WoS	all	22	9	/	/	/	/	/	/	/	/	/	31
	English	21	9	/	/	/	/	/	/	/	/	/	30
Dimensions	all	20	6	/	/	5	/	/	7	/	/	/	38
	English	20	6	/	/	5	/	/	7	/	/	/	38
Scopus	all	47	12	7	1	2	1	/	/	/	/	/	70
	English	42	12	7	1	2	1	/	/	/	/	/	65
PubMed	all	19	7	/	/	/	/	/	/	/	/	/	26
	English	19	7	/	/	/	/	/	/	/	/	/	26
OpenAlex	all	14	8	/	/	/	1	/	/	/	/	/	23
	English	14	8	/	/	/	1	/	/	/	/	/	23
Google Scholar	all	76	51	/	4	7	/	2	/	2	7	1	150
	English	72	51	/	4	7	/	2	/	2	7	1	146

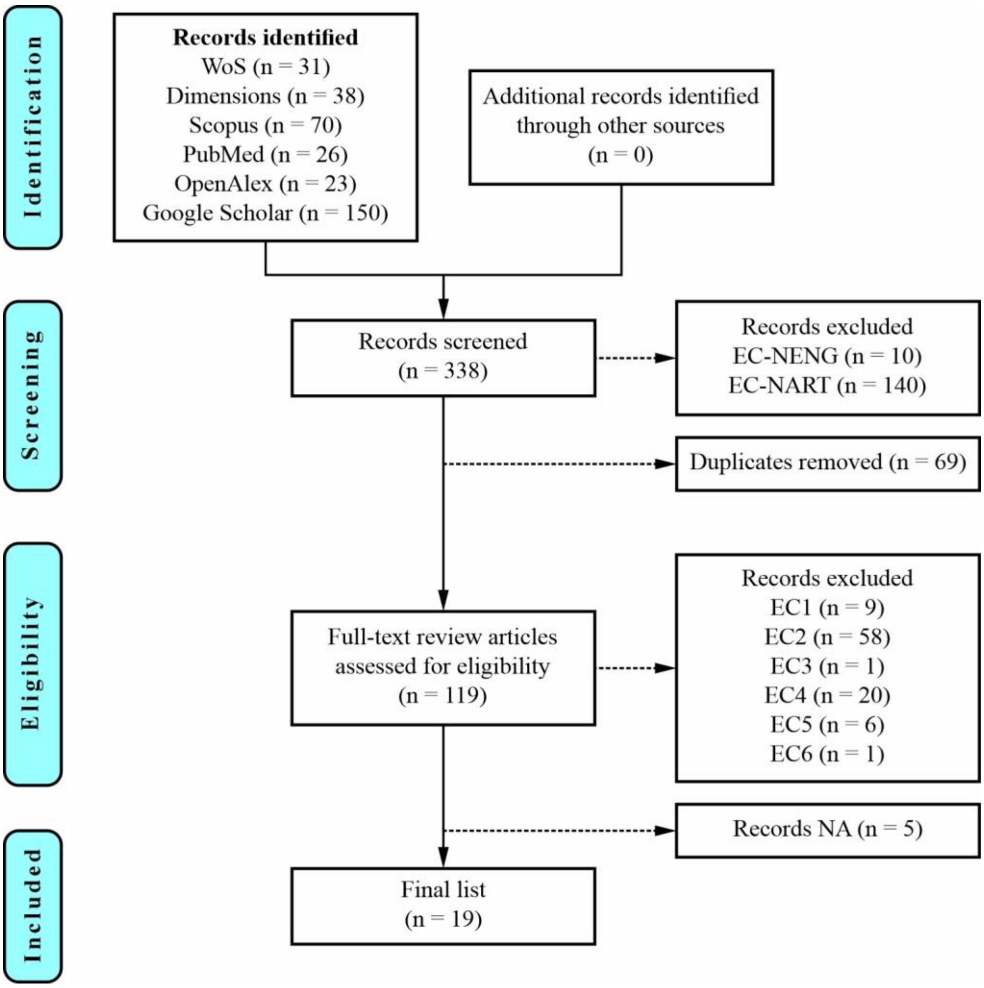

Figure 2. PRISMA flow diagram for retrieval of studies—for more information, please see Table S1.

The extraction of content data included the following: the title of the paper, the journal that the paper was published in, the searched database, the year of publication of the paper, the type of publication (academic article, feasibility study, or in vitro study), the type of dental application, the type of 3D printing technology, the type of material used for fabrication, the advantages and disadvantages of 3D printing technologies, and printed part characteristics (parameters).

After extracting all relevant studies, the authors achieved substantial agreement (Cohen's k = 0.81). However, given the disagreement between reviewers, we performed an objective review analysis, to reach a consensus between reviewers. Namely, given that the studies are extracted independently by two reviewers, additional reviewers who supervised the process gave their own opinions to decide whether a study should be included in the final list of selected studies. After reaching a consensus, we came to the conclusion that indeed 19 studies were relevant. The studies are recorded in an Excel file—please see Table S2, which contains a description of the articles' metadata, content data, and an additional qualitative description of the studies that concern the RQs. The extraction of raw (content) data followed coding for descriptive and inferential analysis. Namely, for answering the proposed RQs, we have used descriptive analysis but extended the analysis using inferential binomial and association statistics to introduce more scientific rigor to the analysis. The analysis of data is performed in SPSS v29.0.1.1, JASP v0.19.3, and Rstudio v.2025.05.1-513.

3. Initial Analysis of the Selected Articles

The initial analysis of the selected articles (n = 19) should provide basic information about AM technologies, materials, and their parameters for a comparison and interpretation of the obtained results.

Nano-material in dental implants from the aspect of composition and biofilm dynamics is presented by Panda et al. [34]; the article considers the biocompatibility of the materials (the ability of the material not to damage the tissue when interacting with the tissue in the human mouth) used in the manufacture of dental implants; the authors performed a 14-day test to form a biofilm that mimics the existence of a natural microorganism to test the cytotoxicity of the tested samples, while DLP technology was used to create the samples. The design of a ceramic composite consisting of two novel components, fluorapatite glass-ceramic (FGC) and yttria-stabilized zirconia (YSZ), is presented by Li et al. [35]; both components are used for dental restoration with excellent results—to make better use of their advantages, the authors created a composite with improved mechanical properties, forming precision and tribological compatibility, while the stereolithography (SLA) technology was used to create the samples. The investigation of the selected alloy elements' effect in an additive manufactured Co-Cr alloy for dental prosthetics is presented by Saha et al. [36]; the study deals with the influence of tungsten and molybdenum in terms of elements added to a Co-Cr alloy for the manufacture of dental implants. To form test samples, the authors used the laser powder directed energy deposition (LP-DED) process and commercially available Co-Cr-W and Co-Cr-Mo alloys; in addition, the structure and hardness of the samples and the obtained excellent results related to wear resistance were tested. The development of a Ti scaffold microstructure by laser powder bed fusion (LPBF) with chemical polishing is presented by Lu et al. [37]; based on the patient's tooth defect model, the authors designed a titanium scaffold. The test samples were made using LPBF technology; the authors used a nitric acid mixed solution to enhance the surface roughness, and as a result, in vitro tests showed that the designed Ti scaffold has excellent biocompatibility with a complete absence of cytotoxicity. A feasibility study regarding 3D printing of ultra-thin veneers made of lithium disilicate using 3D printing technology is presented by Schweiger et al. [38]; test samples with layer thicknesses of down to 0.2 mm were produced using lithography-based ceramic manufacturing (LCM) technology, where the gained thickness allowed for a true non-prep solution or minimally invasive preparation. The characteristics of a novel material—a ceramic-composite resin—that would be used to produce custom dental restorations are given by Stravinskas et al. [39]; the material is intended for SLA 3D printing, where the result would be a restoration with minimal waste. After testing, the tested material showed excellent wear resistance and biocompatibility. An application of the Taguchi method to optimize the FDM process parameters to reduce circularity error and the surface roughness of biomedical implants is given by Balasubramainian et al. [40]; by testing samples obtained by 3D printing, the authors determined that printing speed, temperature, and layer thickness affect the quality of implants. The properties of zirconia-based pastes, for producing ceramics by 3D printing technology, were analyzed by Dimitriadis et al. [41]; Direct Ink Writing (DIW) technology was used to obtain certain properties of zirconia ceramics. The resulting material with the desired mechanical and physical properties would be used for a dental prosthesis, while the tested material is characterized by a low cost and biocompatibility. The evaluation of photopolymer resins for dental prosthetics fabricated via the stereolithography process at different polymerization temperatures is given by Lee et al. [42]; the purpose of this in vitro study was to evaluate the mechanical properties of test samples printed with SLA technology. Test samples in the form of dental prosthetics made of photopolymer were produced at three different temperatures, and as the result, the obtained samples had excellent biocompatibility and wear resistance. The fabrication of color-graded feldspathic dental prosthetics for aesthetic and restorative dentistry is presented by Sutejo et al. [43]; the study refers to the feasibility investigation of natural teeth shades replication on dental prosthetics. The samples were made using functionally graded additive manufacturing (FGAM) technology, while feldspathic porcelain (FP) and yttrium aluminum garnet cerium were used for dental restoration; the applied method was expensive, while the quality of the printed samples was satisfactory. The marginal and internal fit of provisional crowns made using two 3D printing technologies were analyzed by Libonati et al. [44]; using SLA and DLP technologies, 60 test samples of temporary crowns were made. The authors used liquid resin for SLA, while for DLP they used PMMA, and as a result, the tests have shown that crowns produced by DLP have lower precision than crowns produced by SLA. A novel commercially pure titanium alloy for dental prosthetic applications was presented by Barro et al. [45]; using LDED technology, the authors printed samples of the new alloy, after which they compared the characteristics of the samples obtained with samples made using traditional milling. The samples made with the new titanium alloy have better characteristics than traditional milling technology, with lower production costs because the obtained sample does not have to be post-processed. A comparison of test samples made through 3D printing—using SLS and CNC milling technology, for the purpose of application for dental implants and abutments—was performed and presented by Dobrzański et al. [46]; the authors used a Titanium-Ti6Al4V alloy to make the test samples due to its corrosion resistance and good biocompatibility properties. Samples made through 3D printing are more precisely made with lower production costs because the obtained dental implant does not have to be processed afterwards. The fabrication of a customized tooth crown using 3D printing technology is presented by Balasubramani et al. [47]; FDM technology and materials—polyethylene terephthalate glycol (PETG, black in color) and polycyclohexylene dimethylene terephthalate glycol-modified (PCTG, white in color)—were used to fabricate the samples. Using the aforementioned technology and materials, the authors created a multipurpose tooth filling/tooth cap slurry and the resulting samples were tested with the Fourier transform infrared (FTIR) spectrum and an in vitro anti-bacterial study. The fabrication of dental restorative prostheses from metal materials and powdered polymers, using laser-assisted additive technologies, is presented by Moraru et al. [48]; the authors used SLS technology and Co-Cr alloys to create samples—dental prostheses—which they compared with samples produced by DLP technology and DruckWege Type D Dental resin material. The resulting dental prostheses are very precisely made, during production it is not necessary to use supports (as with 3D printing technologies for thermoplastic materials) and no subsequent processing of those parts is necessary, which affects the total production costs. An in vitro study where a new and effective method for producing 3D-printed zirconia laminates in dental restorative prostheses using DLP technology is described and presented by Noh et al. [49]; the authors performed the Shapiro–Wilk, Kolmogorov–Smirnov, and Mann–Whitney tests, and as a result, the gap between the zirconia laminates produced using DLP printing and the subtractive manufacturing method significantly differed only at the mesioincisal measurement point. The effects of surface preparation methods on the color stability of 3D-printed dental restorations is presented by Raszewski et al. [50]; the authors examined the color stability of three resins like Denture 3D+, Crowntec A3, and Crowntec A2 for 3D printing—these materials were used to make dental crowns in A2 and A3 colors through laser directed energy deposition via powder feeding (LDED-PF) technology. The test samples were in the form of incisors: the first group of samples after curing and washing with alcohol was not subjected to any treatment, the second group of samples was covered with a light-curing varnish, while the third group of samples was polished in a standard way; as a result, to minimize color change using these 3D print materials, these materials must undergo complete curing, otherwise the varnish will crack. An in vitro study comparing the misfit of 3D-printed (SLM), milled (CNC manufactured), and lost wax technique (LWT)-fabricated dental crowns, is presented by Al-Saleh et al. [51]; second maxillary premolar teeth were prepared for metal-ceramic crowns and equally divided into three groups for testing purposes. The tests show that fabrication technique and finish line design are critical in reducing the marginal misfit of Co-Cr copings. A novel manufacturing method for dental restoration that combines casting and selective laser melting (SLM) for obtaining one hybrid piece is presented by Uriciuc et al. [52]; by casting Co-Cr inserts on top of dental prosthetic pieces previously manufactured by the SLM of Co-Cr powder (CoMo), the authors gained high precision and high fitting accuracy between the hybrid frameworks. In addition, the process is slow due to the combination of technologies, but since no post-processing is required, it reduces costs.

Based on the initial analysis of the selected articles, we conclude that there are numerous 3D printing technologies, as well as a wide range of different materials to produce dental applications, so the following is a comparison of the characteristics of the materials and 3D printing technologies that affect the quality as well as the safe usage of dental applications.

4. Results

Figure 3 provides a descriptive overview of the distribution of dental applications (Figure 3A), material types (Figure 3B), and 3D printing technologies (Figure 3C) by year of publication. While the results show categorical breakdowns, we emphasize that a single study represents many categories, and thus, visual patterns should be interpreted as exploratory rather than statistically conclusive. With this limited sample, dental restoration and dental prosthetic applications appear more frequently than dental implant and dental crown applications. Biomaterials show a slight upward trend in reported usage, while metals exhibit a modest decline in usage. When it comes to additive technologies, SLS technology was initially the most prevalent, while the introduction of new materials led to the expansion of SLA and DLP, respectively, as well as FDM technology.

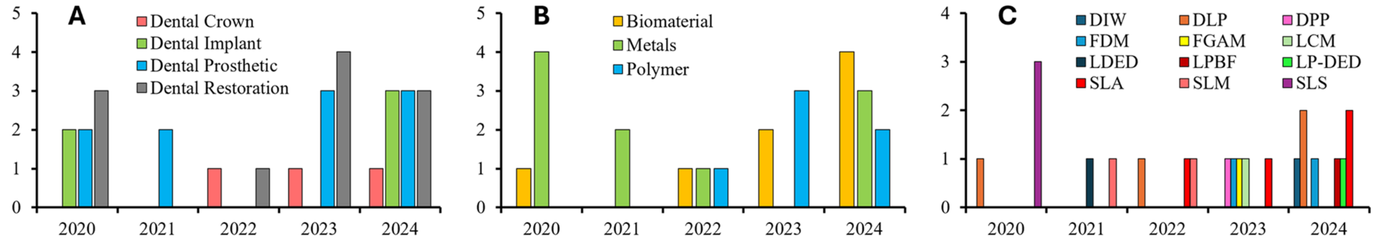

Figure 3. Descriptive analysis of the following: (**A**) dental application; (**B**) material type; and (**C**) 3D printing technologies, represented by the number of articles dealing with these (y-axis) and publication year (x-axis).

Figure 4 shows the Relationship map, i.e., the association between the class categories of dental applications, material, and type of 3D printing technology used in dental applications. The results suggest that "Biomaterials" are strongly associated with "Power Bed Fusion", such as "Dental Restoration" and "Dental Prosthetics". Next, the "Metals" are strongly associated with "Vat Photopolymerization" and "Material Jetting", as well as "Dental Prosthetic" and "Dental Restoration", with less association to "Power Bed Fusion" and "Extrusion". Lastly, "Polymers" show weak association in explaining dental applications compared to "Biomaterials" and "Metals", while also suggesting strong association with "Vat Photopolymerization", but higher association with "Extrusion" 3D printing technology, compared to the other two materials. In sum, from the materials, "Metals" are dominant, while in dental applications "Dental prosthetics" and "Dental restoration" are dominant applications. Therefore, it can be concluded that "Vat Photopolymerization" and "Power Bed Fusion" are dominant groups used in 3D dental applications. It should be noted that "group" implies similar technologies from the aspect of the functioning principle, e.g., technologies that include the use of a laser beam to obtain a finished 3D object, such as SLM, LDED, LP-DED, and SLS.

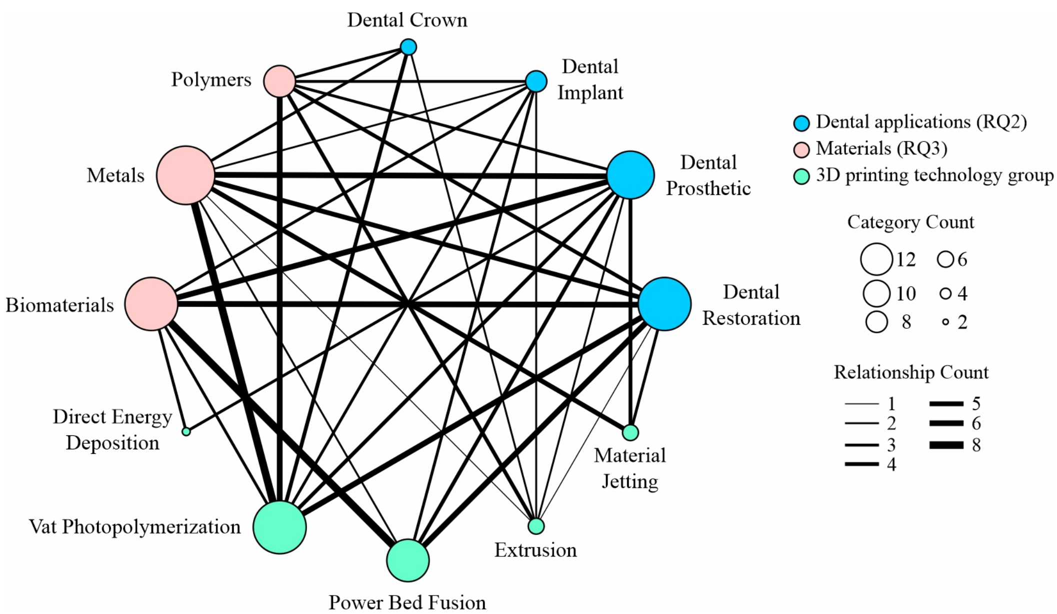

Figure 4. Relationship map between dental applications, materials, and the group of 3D printing technologies used.

Figure 5 shows the considerations of the characteristics of 3D printing technologies and materials in the analyzed articles, subjected to binomial test statistics. The results suggest that there is a lack of considerations (at least $p < 0.05$) in the domains of "Tribological_Test", "Cytotoxicity", "Microbiological_Examination", and "Corrosion_Resistance". It should be noted that the "Corrosion_Resistance" test is only meaningful for dental applications that contain metal materials, while the "Tribological_Test" was used mainly for composite materials. From Figure 5, it can be seen that the "Cytotoxicity" and "Microbiological" tests were not considered in most of the selected articles, although they are two very important parameters. Considering that dental applications are implanted in the patient's mouth (jaw), where there is a permanent process of food digestion under the influence of the bacteria that exist in the mouth, it is necessary to perform microbiological tests to analyze the durability of a material (lifespan) under the influence of bacteria. Cytotoxicity is also a very important parameter because, over time, materials that are potentially dangerous to human health decompose under the influence of a number of factors.

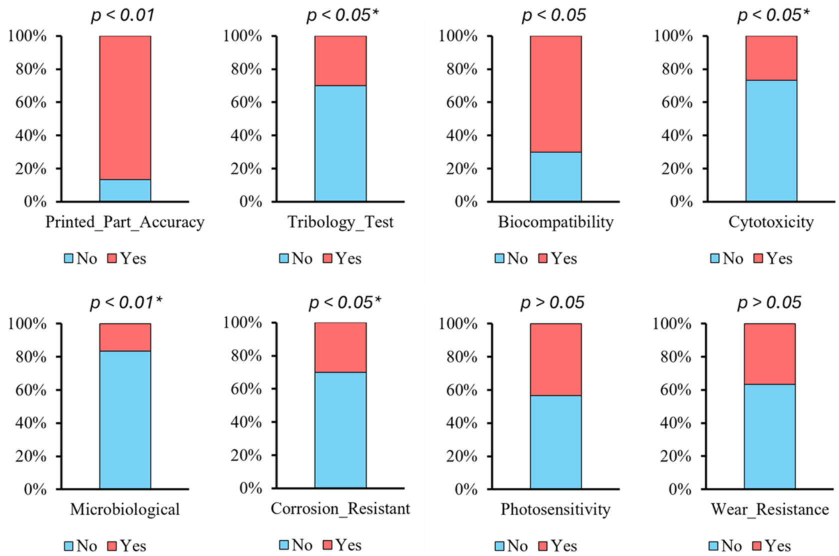

Figure 5. Binomial test of 3D printing considered characteristics and consequences; note: (i) the bar charts represent the binary outcome Y/N, regarding whether or not the authors considered the feature in the analysis, and (ii) the asterisk sign suggests a lack of consideration of statistical significance.

By isolating studies that considered the aspects and characteristics of 3D printing technologies and materials, please see Figure 6, we discuss the importance of printed-part accuracy and wear resistance. Therefore, in the case of printed parts, the results for accuracy are "High/Sufficient" due to the fact that some technologies require post-processing, such as machining by sanding, in order to obtain the highest quality surface after the 3D printing process. Due to the small sample, the analyzed parameters "Wear_Resistance" and "Cytotoxicity" are considered "Excellent/Good" and "Absence of/Low", respectively.

Figure 7 shows the so-called Circos plot—a comprehensive overview of how different materials, 3D printing technologies, and biomedical features are interrelated. The colored links between segments indicate interactions between the categories positioned around the circle. Those categories are grouped as follows: material types (e.g., "Metals", "Polymers", or "Biomaterials"), 3D printing technologies (e.g., "3DPT: SLS" or "3DPT: FDM"), and properties (e.g., "Corrosion_Resistance" or "Wear_Resistance"). The thickness of the links in color indicates stronger or more frequent associations, while the thinner links suggest weaker or less frequent interactions. The thick, colored link from "3DPT: SLS" to "Tribology_Test: Excellent" suggests a strong association between SLS printing technology and excellent tribological characteristics. In addition, the thick link from "3DPT: DLP" to "Photosensitivity: Yes" shows that DLP technology is strongly associated with "Photosensitivity: Yes", while the thin link from "3DPT: DLP" to "Cytotoxicity: Absence of" suggests a weak association between these two.

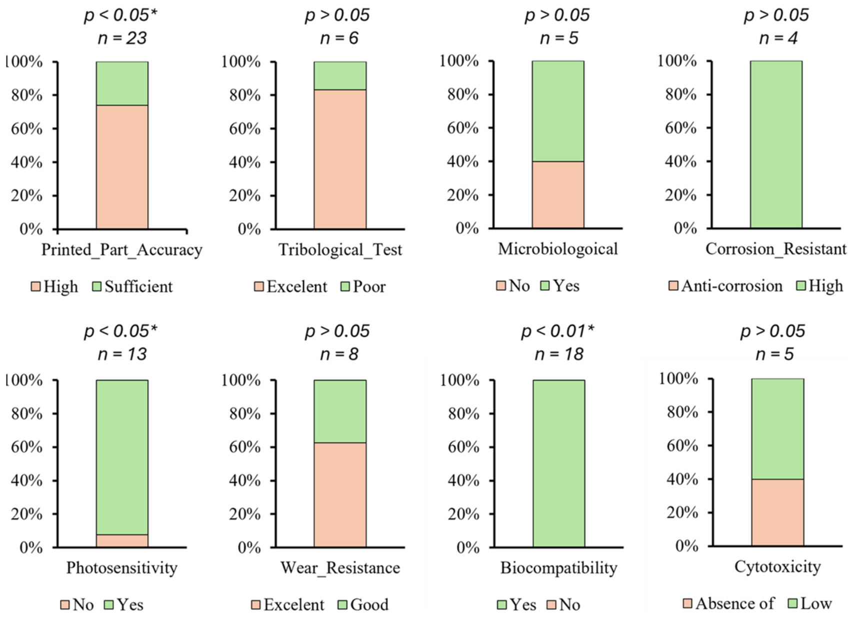

Figure 6. Binomial test of 3D printing considered characteristics and consequences; note: (i) the bar charts represent binary outcomes as a consequence of the use of application properties, and (ii) the asterisk sign represents the discussed application properties.

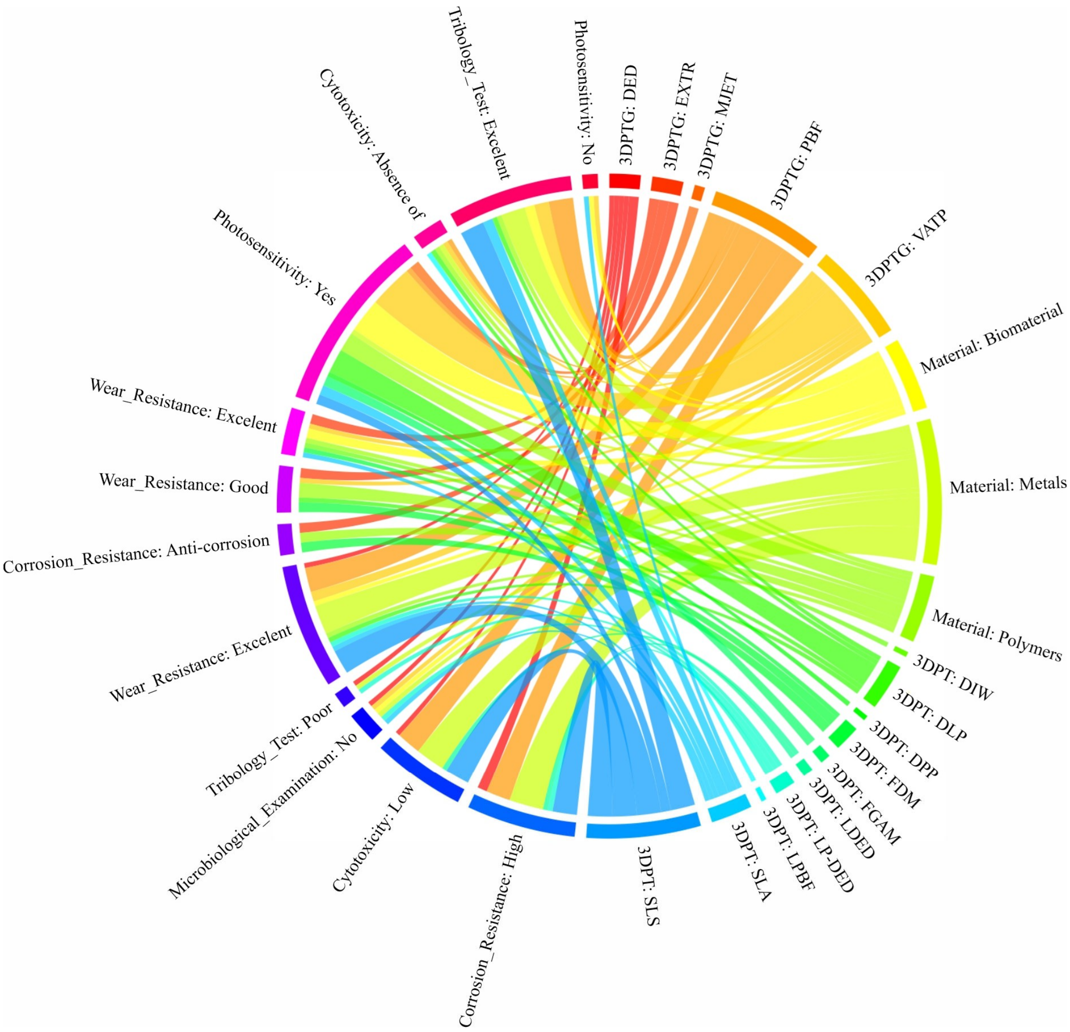

Figure 7. Circos plot of class categories.

5. Discussion

In the following section, we provide an analytical discussion of the results. Namely, Figures 4–7 were designed to synthesize and visualize the potential relationships among additive manufacturing materials, technologies, and dental applications in correspondence to the proposed RQs. These visual and analytical figures aim to support cross-disciplinary insights, particularly from the perspective of engineering and material sciences. Importantly, the grouping of dental applications (e.g., restorations, implants, and graft-related materials) was created based on shared AM material and processing characteristics, rather than specific clinical indications. Thus, while classifications facilitate patterns in technological adoption, we acknowledge their limitations in terms of clinical granularity. For instance, dental prostheses and bone graft scaffolds may share a standard material or printing method (e.g., titanium LPBF), yet serve different therapeutic functions. Hence, the figures should be interpreted as a technology-focused synthesis, rather than a clinical decision-making guide.

The relationship map (Figure 4) shows a pronounced association among biomaterials and power bed fusion technologies, particularly LPBF and SLS, in dental restoration and prosthetic applications. This association is likely due to the superior mechanical performance and biocompatibility that these combinations offer, particularly when precision and load-bearing characteristics are required. This stresses the ability of powder-based methods to produce structurally dense and geometrically complex implants with minimal porosity. Conversely, polymers showed weaker associations across all application domains, which may reflect limitations in their mechanical durability and long-term performance under oral conditions. While polymer-based FDM and DIW offer advantages in terms of low costs and rapid prototyping, they appear less suited for permanent restorative applications, which likely explains their limited presence in the reviewed articles.

The underrepresentation of cytotoxicity and microbiological evaluations (Figure 5) raises serious concerns. Despite their criticality for clinical translation, these parameters are often omitted, possibly due to the high cost and regulatory complexity of in vitro or in vivo validation studies. This gap underscores a potential disconnect between material engineering and biomedical requirements—a recurring challenge in translational research.

Table 2 shows the most commonly used 3D printing technologies in the selected articles from different aspects, such as the characteristics of additive technologies, used materials, applications, and advantages and disadvantages. Summarizing the results, the most prominent advantages of additive technologies in dentistry are as follows: (i) a wide range of materials, (ii) high precision and accuracy of manufacturing, (iii) good for complex geometries, (iv) no need for support structures, and (v) low material waste; whereas the most prominent disadvantages are as follows: (i) lower resolution and surface finish, (ii) material limitations, (iii) post-processing is required, (iv) certain materials are toxic, (v) high costs, and (vi) support structures are required. It is important to note that due to the restricted number of studies obtained through the systematic review, the sample size limits the generalizability of conclusions, and further studies are needed to support inferential statistics, which is why a careful examination and discussion of the findings is performed.

Based on RQ1 (What are the most common applications of additive manufacturing in dentistry?), the literature review and data analysis concluded that additive manufacturing in dentistry is most often used in applications such as dental restoration, dental prosthetics, dental implants, and dental crowns. Regarding RQ2 (Which technologies and materials are most prevalent in dental applications?), the most pervasive technologies are as follows: fused deposition modeling (FDM), stereolithography (SLA), digital light processing (DLP), selective laser sintering (SLS), and laser-directed energy deposition (LDED). Through RQ3

(Which parameters affect the quality and safe usage of 3D printed dental applications?), it was concluded that numerous parameters influence the quality of 3D-printed dental applications, including printed-part accuracy, wear resistance, corrosion resistance, photosensitivity, and post-processing. In addition, the parameters that affect the safe usage of 3D-printed dental applications are biocompatibility and cytotoxicity.

Table 2. The most commonly used 3D printing technologies in the selected articles from different aspects.

3D Printing Technology	Characteristics	Materials	Application	Advantages	Disadvantages	Ref.
Fused Deposition Modeling (FDM)	material extrusion through a nozzle; a heater installed in the printer head melts the filament, then pushes it (mechanically) through the nozzle and stacks it as a layer on the printing bed;	polylactic acid (PLA); Polyethylene Terephthalate Glycol (PETG);	dental implant; dental crown; dental restoration;	low-cost; easy to use; wide range of materials; minimal waste; design flexibility;	lower resolution and surface finish; slow for high-resolution or large parts; support removal can be difficult; parts with accuracy limitationsare weaker along the Z-axis; warping and cracking;	[40,47]
Stereolithography (SLA)	high-power pulsed laser light increases the temperature of specific areas to weld or sinter additional material on a three-axis moving base;	GC-YSZ composite ceramics; ceramic-composite resin Liqcreate Composite-X; ZMD-1000B; liquid resin;	dental restoration; dental prosthetic; dental crown;	high precision and accuracy; high-detail, smooth, and accurate printed parts; good for complex geometries;	material limitations; resins can be toxic; post-processing required; higher operating costs;	[35,39,42,44]
Lithography-based Ceramics Manufacturing (LCM)	uses a photosensitive ceramic suspension—a mixture of ceramic particles and a binder that is cured by light; it cures the material layer by layer using UV light (from a projector or laser), similar to SLA technology; after printing, the binder separation and sintering processes remove the polymer and fuse the ceramic particles into a dense, finished product;	lithium disilicate ceramics	dental prosthetic; dental restoration	high resolution and surface quality; usage of ceramics (Alumina Al_2O_3, Zirconia ZrO_2, Silicon Nitride Si_3N_4, Silicon Carbide SiC); good for complex geometries; ideal for custom products;	high cost; post-processing; material limitations; final part shrinks during sintering; size constraints;	[38]
Digital Light Processing (DLP)	similar to SLA technology, but uses a digital projector to cure photopolymer resin layer by layer instead of a laser;	Tera Harz TC-85 resin—photopolymer; DruckWege Type D Dental resin;	dental implant; dental prosthetic; dental restoration;	high resolution and accuracy; faster than SLA technology; excellent surface finish; wide range of resins;	post-processing required; shrinkage; resins are toxic; resin is more expensive than FDM filament;	[34,48,49]
Daylight Polymer Printing (DPP)	similar to liquid crystal display (LCD) technology, but it uses visible light (daylight spectrum) instead of ultraviolet (UV) to cure photopolymer resin;	commercial resins: Denture 3D+, Crowntec A3, and Crowntec A2;	dental restoration;	low cost of operation; scalability; uses daylight-spectrum light which is less harmful than UV; high detail and surface finish;	requires specific daylight-reactive resins; DPP printers were slower than DLP or SLA due to the nature of daylight curing and resin chemistry; lower mechanical strength;	[50]
Selective Laser Sintering (SLS)	layers of powder are applied sequentially, and each layer is selectively sintered using a laser beam along a predetermined path; the technique is then repeated layer by layer until the intended 3D object is finished;	Ti6AI4V alloy; CoCrW alloy; CoCrMo alloy; zirconia paste (ININI-CERA);	dental restoration; dental prosthetic;	high strength and functionality; excellent design freedom; good surface uniformity; no need for support structures; wide range of materials;	high cost; post-processing required (excavation, cleaning, depowdering); slow cooling times; powder handling requires proper ventilation and safety equipment;	[46,48]

Table 2. *Cont.*

3D Printing Technology	Characteristics	Materials	Application	Advantages	Disadvantages	Ref.
Selective Laser Melting (SLM)	a powerful laser is used to completely melt and fuse metal powder layer by layer into a solid, dense metal part;	CoCr alloy;	dental restoration; dental prosthetic;	the usage of true metal parts; complex geometries; high density and accuracy; ideal for custom implants;	support structures required; very slow build speed; post-processing intensive (heat treatment, support removal, CNC machining, surface polishing); fine metal powders are combustible; very high cost;	[51,52]
Laser-Directed Energy Deposition (LDED)	a form of 3D metal printing that uses a laser to melt a metal raw material, either a powder or wire, as it is deposited onto a substrate; LDED technology builds or repairs metal parts layer by layer and is often used to print large-scale metal structures, repair expensive components, or add features to existing parts;	commercially pure Ti Grade 4 (CP-Ti Grade 4);	dental prosthetic;	lower material waste compared to subtractive methods; ideal for repairing damaged parts; large build volumes; high deposition rates; multi-material capability;	support structures required; high equipment cost; lower resolution and accuracy compared to SLM, DMLS, or LDED printers; requires precise synchronization of laser, powder flow, and motion systems;	[45]
Laser Powder-Directed Energy Deposition (LP-DED)	a subtype of DED that uses a laser as the energy source and metal powder as the raw material to fabricate or repair parts; it is a high-precision process that combines laser melting with precise powder delivery to produce metallurgically bonded metal parts;	CoCrW alloy; CoCrMo alloy;	dental prosthetic;	high precision metal deposition; multi-material structures; large build volumes; minimum waste;	surface finish and resolution; high equipment and operational costs; thermal stresses and distortion can occur; metal powders are hazardous;	[36]
Laser Powder Bed Fusion (LPBF)	high-powered laser selectively melts fine metal powder, layer by layer, to create complex parts directly from a CAD file;	Ti powder (TiCP-grade 2);	dental restoration;	excellent mechanical properties; high precision; complex geometries; wide material compatibility; no tooling required;	slow build speeds; support structures needed; requires post-processing (heat treatment, machining, and surface finishing); high equipment and operational costs;	[37]
Direct Ink Writing (DIW)	viscous „ink" (a paste or gel) is extruded through a nozzle and deposited layer by layer to build 3D structures; the ink is usually a material loaded with particles, polymers, or biological cells, and solidifies or cures after printing;	TZ-3YS-E zirconia powder;	dental prosthetic;	material versatility; low cost; scalability; multi-material printing; direct fabrication scaffolds;	limited resolution; mechanical properties (lower strength); post-processing required (drying, curing, or sintering); slower than powder- or resin-based printing;	[41]
Functionally Graded Additive Manufacturing (FGAM)	technology that produces parts with gradual variations in material composition, microstructure, or properties throughout the volume of the part;	feldspathic porcelain (FP)/yttrium aluminum garnet cerium YAG:Ce (Y-FP);	dental restoration; dental prosthetic;	optimized mechanical strength, wear resistance, thermal conductivity, or biocompatibility where needed; reduced stress concentrations; design freedom;	materials must be compatible in terms of melting points and chemical bonding; complex process control; high cost; limited material combinations.	[43]

A limitation of this review is the limited number of studies in the field of biocompatibility, microbiological impact, and cytotoxicity in 3D-printed dental applications. This certainly does not downplay our findings, as we selectively discussed samples that were sufficient for the analysis (marked "*" in Figures 5 and 6). Biocompatibility and cytotoxicity are crucial parameters that should be tested, as over time, under the influence of various factors, materials that are potentially hazardous to health can break down in the human mouth. Additionally, microbiological influence is crucial when it comes to the quality (damage to materials caused by bacteria over time) of dental applications, as some, such as implants, are surgically installed in the jaw. Therefore, repeating such a procedure would be potentially dangerous for a patient.

6. Conclusions

This manuscript presents a systematic review of the available literature on the topic of 3D printing technologies with a focus on dental applications, according to the WoS, Dimensions, Scopus, PubMed, Open Alex, and Google Scholar databases, and the PRISMA protocol. After the initial search, 19 articles were selected and analyzed in detail. Considering the significant increase in the application of 3D technologies in dentistry over the last few years, we anticipate that this trend will continue to grow rapidly, leading to reduced production costs and improved product quality in the future. The use of different materials, and therefore, different 3D printing technologies, enables a wide range of applications in dentistry. Furthermore, the application of 3D technologies allows the creation of dental applications with highly complex geometry, which are both natural-looking and suitable for installation in the relatively thin jawbone. Given the potential adverse effects of deteriorating printed materials, it is necessary to conduct a future study to determine the impact of embedded applications after a more extended period and their implications for human health.

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/app15158346/s1: Table S1: Inclusion/Exclusion criteria; Table S2: Extracted content data.

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Abbreviations

The following abbreviations are used in this manuscript:

AM	Additive Manufacturing
SLR	Systematic Literature Review
RQ	Research Question
PRISMA	Preferred Reporting of Items for Systematic Reviews and Meta-Analyses

PRISMA	Preferred Reporting of Items for Systematic Reviews and Meta-Analyses
FDM	Fused Deposition Modeling
SLA	Stereolithography
DLP	Digital Light Processing
SLS	Selective Laser Sintering
LDED	Laser-Directed Energy Deposition
CNC	Computer Numerical Control
SLM	Selective Laser Melting
DMLS	Direct Metal Laser Sintering
FFF	Fused Filament Fabrication
PMMA	Polymethyl Methacrylate
CAD/CAM	Computer-Aided Design and Computer-Aided Manufacturing
WoS	Web of Science
EC	Exclusion Criteria
EC-NENG	Exclusion Criteria—Not English
EC-NART	Exclusion Criteria—Not Article
FGC	Fluorapatite Glass-Ceramic
YSZ	Yttria-Stabilized Zirconia
LP-DED	Laser Powder-Directed Energy Deposition
LPBF	Laser Powder Bed Fusion
LCM	Lithography-Based Ceramic Manufacturing
DIW	Direct Ink Writing
FGAM	Functionally Graded Additive Manufacturing
FP	Feldspathic Porcelain
PETG	Polyethylene Terephthalate Glycol
PCTG	Polycyclohexylene Dimethylene Terephthalate Glycol-Modified
FTIR	Fourier Transform Infrared
LDED-PF	Laser Directed Energy Deposition via Powder Feeding
LWT	Lost Wax Technique
PLA	Polylactic Acid
DPP	Daylight Polymer Printing
LCD	Liquid Crystal Display
UV	Ultraviolet

References

1. Dimitrova, M.; Capodiferro, S.; Vlahova, A.; Kazakova, R.; Kazakov, S.; Barile, G.; Corsalini, M. Spectrophotometric analysis of 3D Printed and conventional denture base resin after immersion in different colouring agents—An in vitro study. *Appl. Sci.* **2022**, *12*, 12560. [CrossRef]
2. Sulaiman, M.M.; Fatalla, A.A.; Haider, J. the impact of incorporating grapefruit seed skin particles into 3D-printed acrylic resin on mechanical properties. *Prosthesis* **2024**, *6*, 1420–1436. [CrossRef]
3. Dimitriadis, K.; Agathopoulos, S. Selective laser melting-sintering technology: From dental Co-Cr alloys to dental ceramic materials. *Sol. St. Phen.* **2022**, *339*, 115–122. [CrossRef]
4. Rouf, S.; Malik, A.; Singh, N.; Raina, A.; Naveed, N.; Siddiqui, M.I.; Haq, M.I. Additive manufacturing technologies: Industrial and medical applications. *Sustain. Oper. Comput.* **2022**, *3*, 258–274. [CrossRef]
5. Gobena, S.T.; Woldeyohannes, A.D. Assessments and investigation of process parameter impacts on surface roughness, microstructure, tensile strength, and porosity of 3D printed polyetherether ketone (PEEK) materials. *Results Eng.* **2024**, *24*, 103317. [CrossRef]
6. Dobrzański, L.A.; Dobrzański, L.B.; Dobrzańska-Danikiewicz, A.D.; Dobrzańska, J.; Rudziarczyk, K.; Achtelik-Franczak, A. Non-antagonistic contradictoriness of the progress of advanced digitized production with SARS-CoV-2 virus transmission in the area of dental engineering. *Processes* **2020**, *8*, 1097. [CrossRef]
7. Wechkunanukul, N.; Klomjit, K.; Kumtun, T.; Jaikumpun, P.; Kengtanyakich, S.; Katheng, A. Comparison of mechanical and surface properties between conventional and CAD/CAM provisional restorations. *Eur. J. Dent.* **2025**, *19*, 697–703. [CrossRef]
8. Kumar, M.S.; Kumar, R.; Saini, R.S.; Vyas, R.; Bai, S.; Vaddamanu, S.K. Assessment of marginal fit and accuracy of crowns fabricated using CADCAM milling and 3D printing technology. *J. Pharm. Bioallied Sci.* **2024**, *16*, S3509–S3511. [CrossRef]

9. Quezada, M.M.; Fernandes, C.; Montero, J.; Correia, A.; Salgado, H.; Fonseca, P. A Different approach to analyzing the surface roughness of prosthetic dental acrylic resins. *Appl. Sci.* **2024**, *14*, 619. [CrossRef]
10. Nguyen, M.T.; Vu, T.T.; Nguyen, Q.N. Advanced digital 3D technology in the combined surgery-first orthognathic and clear aligner orthodontic therapy for dentofacial deformity treatment. *Processes* **2021**, *9*, 1609. [CrossRef]
11. Lassila, L.; Mangoush, E.; He, J.; Vallittu, P.K.; Garoushi, S. Effect of post-printing conditions on the mechanical and optical properties of 3d-printed dental resin. *Polymers* **2024**, *16*, 1713. [CrossRef]
12. Dobrzański, L.B. Advanced engineering materials and materials processing technologies in dental implant and prosthetic treatment with clinical cases. *Achiev. Mater. Manuf. Eng.* **2023**, *121*, 7–45. [CrossRef]
13. No-Cortes, J.; Attard, B.; Mifsud, D.P.; Ferreira Lima, J.; Markarian, R.A.; Ayres, A.P.; Cassar, G.; Cortes, A.R.; Attard, N.J. Comparison of 3D-printed single crown outcomes among different computer-aided design software programs. *Int. J. Prosthodont.* **2024**, *37*, 63–70. [CrossRef] [PubMed]
14. Singh, A.B. Transforming healthcare: A review of additive manufacturing applications in the healthcare sector. *Eng. Proc.* **2024**, *72*, 2. [CrossRef]
15. Barbur, I.; Opris, H.; Crisan, B.; Cuc, S.; Colosi, H.A.; Baciut, M.; Opris, D.; Prodan, D.; Moldovan, M.; Crisan, L.; et al. Statistical comparison of the mechanical properties of 3D-printed resin through triple-jetting technology and conventional PMMA in orthodontic occlusal splint manufacturing. *Biomedicines* **2023**, *11*, 2155. [CrossRef] [PubMed]
16. Nezir, M.; Özcan, S.; Atilla, A.O.; Evis, Z. A review, zirconia based dental materials. *J. Aust. Ceram. Soc.* **2025**, *61*, 235–249. [CrossRef]
17. Arossi, G.A.; Abdou, N.A.; Hung, B.; Garcia, I.M.; Zimmer, R.; Melo, M.A. Safety of 3D-printed acrylic resins for prosthodontic appliances: A comprehensive cytotoxicity review. *Appl. Sci.* **2024**, *14*, 8322. [CrossRef]
18. Marin, E.; Lanzutti, A. Biomedical applications of titanium alloys: A comprehensive review. *Materials* **2024**, *17*, 114. [CrossRef]
19. Rezaie, F.; Farshbaf, M.; Dahri, M.; Masjedi, M.; Maleki, R.; Amini, F.; Wirth, J.; Moharamzadeh, K.; Weber, F.E.; Tayebi, L. 3D printing of dental prostheses: Current and emerging applications. *J. Compos. Sci.* **2023**, *7*, 80. [CrossRef]
20. Palanisamy, S. Exploring the horizons of four-dimensional printing technology in dentistry. *Cureus* **2024**, *16*, e58572. [CrossRef]
21. Pordeus, M.D.; Junior, J.F.; Venante, H.S.; da Costa, R.M.; Chocano, A.P.; Porto, V.C. Computer-aided technology for fabricating removable partial denture frameworks: A systematic review and meta-analysis. *J. Prosthet. Dent.* **2022**, *128*, 331–340. [CrossRef]
22. Rus, F.; Neculau, C.; Imre, M.; Duica, F.; Popa, A.; Moisa, R.M.; Voicu-Balasea, B.; Radulescu, R.; Ripszky, A.; Ene, R.; et al. Polymeric materials used in 3DP in dentistry—Biocompatibility testing challenges. *Polymers* **2024**, *16*, 3550. [CrossRef] [PubMed]
23. Ferreira, I.; Teixeira, A.B.; dos Reis, A.C. Organic and inorganic antimicrobials incorporated into acrylic resin: Antimicrobial efficacy and cytotoxicity: A systematic review. *Polym. Bull.* **2024**, *81*, 13391–13418. [CrossRef]
24. Dimitrova, M.; Vlahova, A.; Kalachev, Y.; Zlatev, S.; Kazakova, R.; Capodiferro, S. Recent advances in 3D printing of polymers for application in prosthodontics. *Polymers* **2023**, *15*, 4525. [CrossRef] [PubMed]
25. Rasheed, R.K.; Mansoor, N.S.; Mohammed, N.H.; Qasim, S.S. Subtractive and additive technologies in fixed dental restoration: A systematic review. *J. Tech.* **2023**, *5*, 162–167. [CrossRef]
26. Cai, H.; Xu, X.; Lu, X.; Zhao, M.; Jia, Q.; Jiang, H.-B.; Kwon, J.-S. Dental materials applied to 3D and 4D printing technologies: A review. *Polymers* **2023**, *15*, 2405. [CrossRef]
27. Chuchulska, B.; Dimitrova, M.; Vlahova, A.; Hristov, I.; Tomova, Z.; Kazakova, R. Comparative analysis of the mechanical properties and biocompatibility between CAD/CAM and conventional polymers applied in prosthetic dentistry. *Polymers* **2024**, *16*, 877. [CrossRef]
28. Pituru, S.M.; Greabu, M.; Totan, A.; Imre, M.; Pantea, M.; Spinu, T.; Tancu, A.M.C.; Popoviciu, N.O.; Stanescu, I.-I.; Ionescu, E. A review on the biocompatibility of PMMA-based dental materials for interim prosthetic restorations with a glimpse into their modern manufacturing techniques. *Materials* **2020**, *13*, 2894. [CrossRef]
29. Mirzaali, M.J.; Moosabeiki, V.; Rajaai, S.M.; Zhou, J.; Zadpoor, A.A. Additive manufacturing of biomaterials—Design principles and their implementation. *Materials* **2022**, *15*, 5457. [CrossRef]
30. Saha, S.; Roy, S. Metallic dental implants wear mechanisms, materials, and manufacturing processes: A literature review. *Materials* **2023**, *16*, 161. [CrossRef]
31. Rokaya, D.; Skallevold, H.E.; Srimaneepong, V.; Marya, A.; Shah, P.K.; Khurshid, Z.; Zafar, M.S.; Sapkota, J. Shape memory polymeric materials for biomedical applications: An update. *J. Compos. Sci.* **2023**, *7*, 24. [CrossRef]
32. Alqutaibi, A.Y.; Baik, A.; Almuzaini, S.A.; Farghal, A.E.; Alnazzawi, A.A.; Borzangy, S.; Aboalrejal, A.N.; AbdElaziz, M.H.; Mahmoud, I.I.; Zafar, M.S. Polymeric denture base materials: A review. *Polymers* **2023**, *15*, 3258. [CrossRef]
33. Quirosa-Galán, I.; García-Bravo, S.; Fabara-Rodríguez, A.C.; Rodríguez-Pérez, M.P.; Huertas-Hoyas, E.; Pérez-Corrales, J.; Fernández-Gómez, G.; Donovan, M.; García-Bravo, C. Video games in rehabilitation programs for people with Parkinson's disease: A systematic review. *Appl. Sci.* **2025**, *15*, 311. [CrossRef]
34. Panda, A.; Dyadyura, K.; Ivakhniuk, T.; Hrebenyk, L.; Primova, L. Nano-materials in dental implants-understanding composition and biofilm dynamics. *MM Sci. J.* **2024**, *6*, 8050–8057. [CrossRef]

35. Li, C.; Shen, W.; Wang, S.; Kang, J.; Zhang, Y.; Wang, G. Design and 3D printing of glass-ceramic/zirconia composite ceramics for dental application. *Ceram. Int.* **2024**, *50*, 42593–42606. [CrossRef]
36. Saha, S.; Grandhi, M.; Kiran, K.U.; Liu, Z.; Roy, S. Investigating the effect of select alloying elements in additively manufactured Co-Cr alloy for dental prosthetics. *J. Mater. Process. Tech.* **2024**, *329*, 118434. [CrossRef]
37. Lu, C.; Chen, J.; Ma, T.; Chen, Y.; Zeng, D.; Gan, Y.; Yang, Y. Microstructure development of Ti scaffold by laser powder bed fusion with chemical polishing and its mechanical properties, biocompatibility. *Biosurf. Biotribol.* **2024**, *10*, 52–62. [CrossRef]
38. Schweiger, J.; Edelhoff, D.; Schubert, O. 3D printing of ultra-thin veneers made of lithium disilicate using the LCM method in a digital workflow: A feasibility study. *J. Esthet. Restor. Dent.* **2024**, *36*, 588–594. [CrossRef]
39. Stravinskas, K.; Shahidi, A.; Kapustynskyi, O.; Matijošius, T.; Vishniakov, N.; Mordas, G. Characterization of SLA-printed ceramic composites for dental restorations. *Lith. J. Phys.* **2024**, *64*, 203–213. [CrossRef]
40. Balasubramainian, N.K.; Kothandaraman, L.; Sathish, T.; Giri, J.; Ammarullah, M.I. Optimization of process parameters to minimize circularity error and surface roughness in fused deposition modelling (FDM) using Taguchi method for biomedical implant fabrication. *Adv. Manuf.-Polym. Compos. Sci.* **2024**, *10*, 2406156. [CrossRef]
41. Dimitriadis, K.; Baciu, D.; Koltsakidis, S.; Tzetzis, D.; Garmpi, E.; Roussi, E.; Kitsou, I.; Tsetsekou, A.; Andreouli, C.D. Additive manufacturing of zirconia-based pastes for dental prosthesis via robocasting method. *J. Mater. Eng. Perform.* **2025**, *34*, 4735–4749. [CrossRef]
42. Lee, J.M.; Son, K.; Lee, K.B. Evaluation of photopolymer resins for dental prosthetics fabricated via the stereolithography process at different polymerization temperatures—Part I: Conversion rate and mechanical properties. *J. Prosthet. Dent.* **2024**, *131*, 166.e1–166.e9. [CrossRef]
43. Sutejo, I.A.; Kim, J.; Zhang, S.; Gal, C.W.; Choi, Y.J.; Park, H.; Yun, H.S. Fabrication of color-graded feldspathic dental prosthetics for aesthetic and restorative dentistry. *Dent. Mater.* **2023**, *39*, 568–576. [CrossRef]
44. Libonati, A.; Di Taranto, V.; Gallusi, G.; Dolci, A.; Montemurro, E.; Campanella, V. Evaluation of the marginal and internal fit of provisional crown fabricated with two different 3D printing technologies. *J. Biol. Reg. Homeos. Ag.* **2022**, *36*, 49–55. [CrossRef]
45. Barro, Ó.; Arias-González, F.; Lusquiños, F.; Comesaña, R.; del Val, J.; Riveiro, A.; Badaoui, A.; Gómez-Baño, F.; Pou, J. Improved commercially pure titanium obtained by laser directed energy deposition for dental prosthetic applications. *Metals* **2021**, *11*, 70. [CrossRef]
46. Dobrzański, L.A.; Dobrzański, L.B.; Achtelik-Franczak, A.; Dobrzańska, J. Application solid laser-sintered or machined Ti6Al4V alloy in manufacturing of dental implants and dental prosthetic restorations according to Dentistry 4.0 concept. *Processes* **2020**, *8*, 664. [CrossRef]
47. Balasubramani, G.; Nisitha, S.; Pradeep, P.J. 3D dental prosthetic tooth crown: Re-modeling of customized tooth crown using additive manufacturing and synthesis of bio-compactible tooth filling. *Int. J. Innov. Sci. Res. Technol.* **2023**, *8*, 759–766. [CrossRef]
48. Moraru, E.; Dontu, O.; Rizescu, C.; Spanu, A.; Ciobanu, R.; Draghici, C. Laser-assisted additive technologies for the execution of dental restorative prostheses. *IOP Conf. Ser.-Mater. Sci. Eng.* **2020**, *997*, 012050. [CrossRef]
49. Noh, M.; Kim, J. A comparison of internal, marginal, and incisal gaps in zirconia laminates fabricated using subtractive manufacturing and 3D printing methods. *Biomimetics* **2024**, *9*, 728. [CrossRef] [PubMed]
50. Raszewski, Z.; Chojnacka, K.; Mikulewicz, M. Effects of surface preparation methods on the color stability of 3D-printed dental restorations. *J. Funct. Biomater.* **2023**, *14*, 257. [CrossRef]
51. Al-Saleh, S.; Vohra, F.; Albogami, S.M.; Alkhammash, N.M.; Alnashwan, M.A.; Almutairi, N.S.; Aali, K.A.; Alrabiah, M.; Abduljabbar, T. Marginal misfit of 3D-printed (selective laser sintered), CAD-CAM and lost wax technique cobalt chromium copings with shoulder and chamfer finish lines: An in-vitro study. *Medicina* **2022**, *58*, 1313. [CrossRef] [PubMed]
52. Uriciuc, W.A.; Vermesan, H.; Tiuc, A.E.; Ilea, A.; Bosca, A.B.; Popa, C.O. Casting over metal method used in manufacturing hybrid cobalt-chromium dental prosthetic frameworks assembles. *Materials* **2021**, *14*, 539. [CrossRef] [PubMed]