The Advancement of 3D Printing Technology in Dentistry

Subjects: Social Sciences, Mathematical Methods

Contributor: Peace Y. L. Liu , James J. H. Liou , Sun-Weng Huang

Because digitization accelerates product design and reduces development time, 3D printing can meet the demand for small-batch production and customization. This technology has been widely applied in various fields, such as automotive parts production, electronic parts, the aerospace industry, construction, food, and agriculture. 3D printing technology is suitable for application in advancing digitization in dentistry.

3D Printing barriers dentistry additive manufacturing

1. Introduction

Additive manufacturing (also known as 3D printing) is a way to stack materials layer by layer to complete product manufacturing [1]. Unlike traditional manufacturing methods, such as forming, casting, and reduction manufacturing, 3D printing technology can provide design and manufacturing advantages for products with complex structural designs, considerable material savings, flexible and efficient production processes, as well as customization for the customers [2][3] In recent years, the application and development of 3D printing technology have become mature, which can save material consumption and thus reduce production costs [4]. Because digitization accelerates product design and reduces development time, 3D printing can meet the demand for small-batch production and customization [5]. This technology has been widely applied in various fields, such as automotive parts production [6], electronic parts [7], the aerospace industry [8], construction [9], food [10], and agriculture [11].

Although 3D printing technology is one of the most important innovations in various industries, its use in the medical field is still limited. 3D printing technology has the following characteristics for medical applications: (1) the ability to customize for individual patient needs [12], (2) the ability to improve precision and patient comfort through digital devices [13], and (3) the ability to reduce material waste in the manufacturing process [14]. Because of the aforementioned properties, 3D printing has been introduced to dentistry in recent years. Liaw and Guvendiren [15] pointed out that 3D printing technology is characterized by high tunability and complexity and enabling the production of anatomically matched and patient-specific devices. This makes it very suitable for the introduction of digitalization in dentistry. Their study also showed that (1) improving print quality, accuracy, and print speed, (2) developing and integrating more application materials, and (3) eliminating time-consuming and dangerous post-processing procedures will be challenges for 3D printing technology in the future dental field. However, its use in the dental field is not as popular as expected [16]. Past studies have focused on material applications [17] and technological improvements and enhancements [18]. The discussion on the barriers that dentistry encounters when introducing 3D printing is rather limited. Loges and Tiberius [16] used a Ranking-Type Delphi study to investigate the key barriers to implementing 3D printing technology among dentists, dental technologists, and vendors selling 3D printing equipment. Their results showed that (1) lack of relevant knowledge, (2) lack of re-enhancement of employee education and training, (3) willingness to use only traditional methods, and (4) high investment costs combine to be the challenges. From their study, some barriers to the application of 3D printing technology in dentistry were identified. However, among these barriers, there are often many mutual influence relationships. The objectives of this study include the exploration of what the barriers to the application of 3D printing technology in dentistry are. What are their mutual influence relationships? Which barriers are the key core of the influences? Understanding these issues appears to be a key factor in accelerating the digital transformation of dentistry.

There are many methods to investigate the mutual influence relationships among factors, such as principal component analysis [19] and structural equation modeling (SEM) [20]. In recent years, there have been an increasing number of studies using the decision-making and trial assessment laboratory (DEMATEL) technique to explore the influential relationships among barriers, such as women entrepreneurship [21], green lean practices [22], electric vehicle [23], e-commerce technology in SMEs [24], social banking systems [25], construction program manager selection in China [26], risk analysis of maritime transportation [27], etc. Regarding the food industry, Novel Taguchi scheme-based DEMATEL is applied to discuss the performance index of system maintenance [28]. In addition, during the period of COVID-19 spread, DEMATEL has been used to research the tie between the patient's willingness to employ mobile health treatment and the service quality [29].

DEMATEL has the following advantages: (1) It can effectively analyze the direct or indirect effects among different factors and understand the complex cause-and-effect relationships; (2) It can visualize the mutual relationships among the factors through an Influential Network Relationship Map (INRM), enabling decision-makers to clearly understand which factors influence each other; (3) It can also be used to determine the ranking of alternative solutions and at the same time to identify key assessment criteria and measure the weights of the assessment criteria [30]. So this research uses DEMATEL to explore the cause-and-effect relationships between barriers. However, the decision-making process of DEMATEL relies heavily on an expert decision-making system, so the information for decision-making is uncertain and inconsistent because experts often have different preferences regarding different experiences and backgrounds [31]. To remedy these problems, this study proposes using rough-Z numbers to overcome these drawbacks. The rough set can be used as an effective tool to resolve uncertainty and inconsistency, and the advantage of Z-numbers is the integration of experts' judgments and their confidence in the assessment, which can help resolve the uncertainty in decision-making [13]. The proposed rough-Z-number can integrate opinions among experts and overcome inconsistent and uncertain judgments.

2. The Advancement of 3D Printing Technology in Dentistry

2.1. Development and Application of 3D Printing

3D printing technology is a manufacturing method that constructs one layer of material at a time and adds multiple layers of material to form the desired object based on demand [32]. According to the Wohler's Report [33], despite the influence of COVID-19 on the global economy in 2020, 3D printing technology grew by 7.5%, reaching a market size of $12.8 billion. After more than 40 years of development, 3D printing technology has been continuously developed and improved. According to the American Society for Testing and Materials (ASTM), there are seven types of additive manufacturing (AM), including VAT Photopolymerization, Material Jetting, Binder Jetting, Material Extrusion, Powder Bed Fusion, Sheet Lamination, and Direct Energy Deposition [4]. In response to the nature of 3D printing technology, there are also innovative developments in the materials already used. For example, composite materials for the aerospace industry are widely used because of their specific strength, high stiffness, resistance to corrosion, and endurance performance [34]. In the construction industry, suitable combinations of additives have been proposed for incorporation into hybrid soils for 3D printing [35]. In the medical industry, composite materials have been developed by combining different types of materials, such as ceramics and metal materials and ceramics and polymer materials for orthopedic treatment [36]. The application of 3D printing technology is becoming more and more widespread in various industries, such as the manufacturing industry for the production of mold-making models and robotic structural parts [4], the food industry for the rapid production of military food in the battlefield [37], the construction industry for new methods using 3D printing technology for concrete [9], and the construction industry for new methods using 3D printing technology [9], and in the textile industry, the production of special textiles with thermal conductivity and intelligence [38], which shows the wide range of applications and importance of 3D printing technology in various industries.

As customers' expectations for products become diverse, companies have moved from large-scale mass production to small-batch orders. The fourth industrial revolution [39], also known as Industry 4.0, is taking shape as network infrastructure becomes widespread and innovations in hardware and software are integrated into the manufacturing industries. With the emergence of digital technologies, such as the Internet of Things [40], robotics [41], 3D printing [4], Artificial Intelligence [42], blockchain [43], and virtual reality [44], and their gradual application in various areas, it has led to the revolutionary development of digital transformation in the global manufacturing industry. It should be noted that the emergence of 3D printing technology has attracted people's attention.

2.2. Development of 3D Printing in the Medical Field

The application of 3D printing technology in the medical field has also been described in recent years, such as the creation of surgical tools and prostheses tailored to individual patient needs [45], bioprinting to create artificial skin for the treatment of burns [46], and the creation of synthetic organs [47]. 3D printing technology has also improved medical education by allowing medical students to learn medical knowledge through human anatomy [48]. Actually, digital 3D simulations created by 3D printing technology can improve the quality and efficiency of learning [49][50]. In the field of dentistry, 3D printing technology is used to create full dentures without the use of traditional manufacturing techniques and tools, such as molds, cutting tools, or tooling fixtures [51]. 3D printing technology provides dental students with digital models of teeth and mouths for clinical dental training [52].

2.3. Barriers to the Advancement of 3D Printing

The development and application of 3D printing technology in various industries are booming, but what are the barriers to its application in the dental field that make it less common than expected? What are the mutual influence relationships among these barriers? In this study, DEMATEL was used to investigate and propose ways to address and improve the situation. From the preliminary literature review, the possible barriers to the advancement of 3D printing technology in dentistry are summarized in **Table 1**.

Table 1. Barriers to the advancement of 3D printing in dentistry.

Barrier	References	Barrier	References
Cumbersome processes	[15]	Economic benefits	[15]
Post-processing steps	[15]	Equipment cleaning and disinfection	[15]
Limited clinical cases	[15]	Not familiar with new technology	[16]
Collaboration capability	[16]	Management process responsiveness	[53]
Consensus within the organization	[53]	Technology integration	[53]
Conservative attitude	[53]	Government’s attitude	[53]
Managerial support	[53]	High installation cost	[2][53]
Suitability of raw materials	[53][54]	Financial benefit assessment	[55]
Regulations and management	[56]	Intellectual property	[56]
Accuracy improvement	[54]	Education and training	[15][57][58]
Equipment intellectualization	[59]	Technical talents	[60]
Material supply chain	[61]	Hidden costs of new technology	[61]
Protocol standardization	[61]	Corresponding infrastructure	[59][62]
Material limitations	[2][16][63]	Technology optimization	[16][58][63]
Information security	[64]	Technology maturity	[59][64]

References

1. Naveed, N. Investigate the effects of process parameters on material properties and microstructural changes of 3D-printed specimens using fused deposition modelling (FDM). Mater. Technol. 2021, 36, 317–330.

2. Ngo, T.D.; Kashani, A.; Imbalzano, G.; Nguyen, K.T.; Hui, D. Additive manufacturing (3D printing): A review of materials, methods, applications and challenges. Compos. Part B Eng. 2018, 143, 172–196.
3. Gal, M.S. 3D Challenges: Ensuring Competition and Innovation in 3D Printing. Vanderbilt J. Entertain. Technol. Law 2019, 22, 1.
4. Jandyal, A.; Chaturvedi, I.; Wazir, I.; Raina, A.; Haq, M.I.U. 3D printing—A review of processes, materials and applications in industry 4.0. Sustain. Oper. Comput. 2022, 3, 33–42.
5. Bertling, J.; Rommel, S. A critical view of 3D printing regarding industrial mass customization versus individual desktop fabrication. In The Decentralized and Networked Future of Value Creation; Springer: Cham, Switzerland, 2016; pp. 75–105.
6. Nichols, M.R. How does the automotive industry benefit from 3D metal printing. Met. Powder Rep. 2019, 74, 257–258.
7. Goh, G.L.; Zhang, H.; Chong, T.H.; Yeong, W.Y. 3D printing of multilayered and multimaterial electronics: A review. Adv. Electron. Mater. 2021, 7, 2100445.
8. Mieloszyk, J.; Tarnowski, A.; Kowalik, M.; Perz, R.; Rzadkowski, W. Preliminary design of 3D printed fittings for UAV. Aircr. Eng. Aerosp. Technol. 2019, 91, 756–760.
9. Tay, Y.W.D.; Panda, B.; Paul, S.C.; Noor Mohamed, N.A.; Tan, M.J.; Leong, K.F. 3D printing trends in building and construction industry: A review. Virtual Phys. Prototyp. 2017, 12, 261–276.
10. Nachal, N.; Moses, J.A.; Karthik, P.; Anandharamakrishnan, C. Applications of 3D printing in food processing. Food Eng. Rev. 2019, 11, 123–141.
11. Crisostomo, J.L.B.; Dizon, J.R.C. 3D Printing Applications in Agriculture, Food Processing, and Environmental Protection and Monitoring. Advance Sustainable Science, Eng. Technol. 2021, 3, 0210201.
12. Nesic, D.; Schaefer, B.M.; Sun, Y.; Saulacic, N.; Sailer, I. 3D printing approach in dentistry: The future for personalized oral soft tissue regeneration. J. Clin. Med. 2020, 9, 2238.
13. Ahmadi, H.B.; Lo, H.W.; Pourhejazy, P.; Gupta, H.; Liou, J.J. Exploring the mutual influence among the social innovation factors amid the COVID-19 pandemic. Appl. Soft Comput. 2022, 125, 109157.
14. Ford, S.; Despeisse, M. Additive manufacturing and sustainability: An exploratory study of the advantages and challenges. J. Clean. Prod. 2016, 137, 1573–1587.
15. Liaw, C.Y.; Guvendiren, M. Current and emerging applications of 3D printing in medicine. Biofabrication 2017, 9, 024102.

16. Loges, K.; Tiberius, V. Implementation Challenges of 3D Printing in Prosthodontics: A Ranking-Type Delphi. Materials 2022, 15, 431.
17. Revilla-León, M.; Sadeghpour, M.; Özcan, M. An update on applications of 3D printing technologies used for processing polymers used in implant dentistry. Odontology 2020, 108, 331–338.
18. Kessler, A.; Hickel, R.; Reymus, M. 3D printing in dentistry—State of the art. Oper. Dent. 2020, 45, 30–40.
19. Mahmoudi, M.R.; Heydari, M.H.; Qasem, S.N.; Mosavi, A.S.; Band, S. Principal component analysis to study the relations between the spread rates of COVID-19 in high risks countries. Alex. Eng. J. 2021, 60, 457–464.
20. Hasegawa, Y.; Lau, S.K. Comprehensive audio-visual environmental effects on residential soundscapes and satisfaction: Partial least square structural equation modeling approach. Landsc. Urban Plan. 2022, 220, 104351.
21. Raghuvanshi, J.; Agrawal, R.; Ghosh, P.K. Analysis of barriers to women entrepreneurship: The DEMATEL approach. J. Entrep. 2017, 26, 220–238.
22. Singh, C.; Singh, D.; Khamba, J.S. Analyzing barriers of Green Lean practices in manufacturing industries by DEMATEL approach. J. Manuf. Technol. Manag. 2020, 32, 176–198.
23. Asadi, S.; Nilashi, M.; Iranmanesh, M.; Ghobakhloo, M.; Samad, S.O.; Alghamdi, A.; Mohd, S. Drivers and barriers of electric vehicle usage in Malaysia: A DEMATEL approach. Resour. Conserv. Recycl. 2022, 177, 105965.
24. Yadav, H.; Soni, U.; Gupta, S.; Kumar, G. Evaluation of Barriers in the Adoption of E-Commerce Technology in SMEs: A Fuzzy DEMATEL Approach. J. Electron. Commer. Organ. 2022, 20, 1–18.
25. Özdemirci, F.; Yüksel, S.; Dinçer, H.; Eti, S. An assessment of alternative social banking systems using T-Spherical fuzzy TOP-DEMATEL approach. Decis. Anal. J. 2023, 6, 100184.
26. Yan, H.; Yang, Y.; Lei, X.; Ye, Q.; Huang, W.; Gao, C. Regret Theory and Fuzzy-DEMATEL-Based Model for Construction Program Manager Selection in China. Buildings 2023, 13, 838.
27. Kuzu, A.C. Application of fuzzy DEMATEL approach in maritime transportation: A risk analysis of anchor loss. Ocean Eng. 2023, 273, 113786.
28. Maduekwe, V.C.; Oke, S.A. Novel Taguchi scheme–based DEMATEL methods and DEMATEL method for the principal performance indicators of maintenance in a food processing industry. Int. J. Intell. Comput. Cybern. 2021, 14, 363–397.
29. Alzahrani, A.I.; Al-Samarraie, H.; Eldenfria, A.; Dodoo, J.E.; Alalwan, N. Users’ intention to continue using mHealth services: A DEMATEL approach during the COVID-19 pandemic. Technol. Soc. 2022, 68, 101862.

30. Si, S.L.; You, X.Y.; Liu, H.C.; Zhang, P. DEMATEL technique: A systematic review of the state-of-the-art literature on methodologies and applications. Math. Probl. Eng. 2018, 2018, 3696457.
31. Jiang, S.; Shi, H.; Lin, W.; Liu, H.C. A large group linguistic Z-DEMATEL approach for identifying key performance indicators in hospital performance management. Appl. Soft Comput. 2020, 86, 105900.
32. Khan, I.H.; Javaid, M. Role of Internet of Things (IoT) in adoption of Industry 4.0. J. Ind. Integr. Manag. 2021, 7, 515–533.
33. Richert, A.; Shehadeh, M.; Müller, S.; Schröder, S.; Jeschke, S. Robotic workmates: Hybrid human-robot-teams in the industry 4.0. In International Conference on e-Learning; Academic Conferences International Ltd.: Reading, UK, 2016; p. 127.
34. Bécue, A.; Praça, I.; Gama, J. Artificial intelligence, cyber-threats and Industry 4.0: Challenges and opportunities. Artif. Intell. Rev. 2021, 54, 3849–3886.
35. Bodkhe, U.; Tanwar, S.; Parekh, K.; Khanpara, P.; Tyagi, S.; Kumar, N.; Alazab, M. Blockchain for industry 4.0: A comprehensive review. IEEE Access 2020, 8, 79764–79800.
36. Masood, T.; Egger, J. Augmented reality in support of Industry 4.0-Implementation challenges and success factors. Robot. Comput. Integr. Manuf. 2019, 58, 181–195.
37. Dawood, A.; Marti, B.M.; Sauret-Jackson, V.; Darwood, A. 3D printing in dentistry. Br. Dent. J. 2015, 219, 521–529.
38. Wohlers, T. Wohlers Report 2021: 3D Printing and Additive Manufacturing Global State of the Industry; Wohlers Associates: Washington, DC, USA, 2021.
39. Ishikawa, E. Toyota Production System—From Recall Crisis to Recovery. In Overcoming Crisis: Case Studies of Asian Multinational Corporations; World Scientific Publishing Co Pte Ltd.: Singapore, 2023; pp. 157–169.
40. Ranjan, R.; Kumar, D.; Kundu, M.; Moi, S.C. A critical review on Classification of materials used in 3D printing process. Mater. Today Proc. 2022, 61, 43–49.
41. Dvorkin, L.; Marchuk, V.; Hager, I.; Maroszek, M. Design of Cement–Slag Concrete Composition for 3D Printing. Energies 2022, 15, 4610.
42. Li, B.; Zhang, M.; Lu, Q.; Zhang, B.; Miao, Z.; Li, L.; Liu, P. Application and Development of Modern 3D Printing Technology in the Field of Orthopedics. BioMed Res. Int. 2022, 2022, 8759060.
43. Liu, Z.; Zhang, M.; Bhandari, B.; Wang, Y. 3D printing: Printing precision and application in food sector. Trends Food Sci. Technol. 2017, 69, 83–94.

44. Xiao, Y.Q.; Kan, C.W. Review on Development and Application of 3D-Printing Technology in Textile and Fashion Design. Coatings 2022, 12, 267.
45. Aimar, A.; Palermo, A.; Innocenti, B. The role of 3D printing in medical applications: A state of the art. J. Healthc. Eng. 2019, 2019, 5340616.
46. He, P.; Zhao, J.; Zhang, J.; Li, B.; Gou, Z.; Gou, M.; Li, X. Bioprinting of skin constructs for wound healing. Burns Trauma 2018, 6, 5.
47. Ji, S.; Guvendiren, M. Recent advances in bioink design for 3D bioprinting of tissues and organs. Front. Bioeng. Biotechnol. 2017, 5, 23.
48. Walker, V. Implementing a 3D printing service in a biomedical library. J. Med. Libr. Assoc. 2017, 105, 55.
49. Wang, K.; Wu, C.; Qian, Z.; Zhang, C.; Wang, B.; Vannan, M.A. Dual-material 3D printed metamaterials with tunable mechanical properties for patient-specific tissue-mimicking phantoms. Addit. Manuf. 2016, 12, 31–37.
50. Lim, K.H.A.; Loo, Z.Y.; Goldie, S.J.; Adams, J.W.; McMenamin, P.G. Use of 3D printed models in medical education: A randomized control trial comparing 3D prints versus cadaveric materials for learning external cardiac anatomy. Anat. Sci. Educ. 2016, 9, 213–221.
51. Shah, S.S.; Pirayesh, A.; Fatahi Valilai, O. Using Blockchain Technology for 3D Printing in Manufacturing of Dental Implants in Digital Dentistry. In Flexible Automation and Intelligent Manufacturing: The Human-Data-Technology Nexus: Proceedings of FAIM 2022, Detroit, MI, USA, 19–23 June 2022; Springer: Cham, Switzerland, 2022; Volume 2, pp. 565–572.
52. Pillai, S.; Upadhyay, A.; Khayambashi, P.; Farooq, I.; Sabri, H.; Tarar, M.; Tran, S.D. Dental 3D-printing: Transferring art from the laboratories to the clinics. Polymers 2021, 13, 157.
53. Yeh, C.C.; Chen, Y.F. Critical success factors for adoption of 3D printing. Technol. Forecast. Soc. Chang. 2018, 132, 209–216.
54. Despeisse, M.; Baumers, M.; Brown, P. Unlocking value for a circular economy through 3D printing: A research agenda. Technol. Forecast. Soc. Chang. 2017, 115, 75–84.
55. Kumar, G.; Bakshi, A.; Khandelwal, A.; Panchal, A.; Soni, U. Analyzing Industry 4.0 Implementation Barriers in Indian SMEs. J. Ind. Integr. Manag. 2022, 7, 153–169.
56. Verma, V.K.; Kamble, S.S.; Ganapathy, L.; Belhadi, A.; Gupta, S. 3D Printing for sustainable food supply chains: Modelling the implementation barriers. Int. J. Logist. Res. Appl. 2022, 2022, e2037125.
57. Thomas-Seale, L.E.; Kirkman-Brown, J.C.; Attallah, M.M.; Espino, D.M.; Shepherd, D.E. The barriers to the progression of additive manufacture: Perspectives from UK industry. Int. J. Prod. Econ. 2018, 198, 104–118.

58. Shahrubudin, N.; Koshy, P.; Alipal, J.; Kadir, M.H.A.; Lee, T.C. Challenges of 3D printing technology for manufacturing biomedical products: A case study of Malaysian manufacturing firms. Heliyon 2020, 6, e03734.
59. Rymarczyk, J. The Change in the Traditional Paradigm of Production under the Influence of Industrial Revolution 4.0. Businesses 2022, 2, 188–200.
60. Stornelli, A.; Ozcan, S.; Simms, C. Advanced manufacturing technology adoption and innovation: A systematic literature review on barriers, enablers, and innovation types. Res. Policy 2021, 50, 104229.
61. Woodson, T.T.; Alcantara, J.T.; do Nascimento, M.S. Is 3D printing an inclusive innovation?: An examination of 3D printing in Brazil. Technovation 2019, 80, 54–62.
62. Hosseini, S.; Halvaei, M.; Ebrahimi, A.; Shamekhi, M.A.; Baghaban Eslaminejad, M. 3D Printing in Dentistry. In Applications of Biomedical Engineering in Dentistry; Springer: Cham, Switzerland, 2020; pp. 195–221.
63. Attaran, M. 3D Printing: Enabling a new era of opportunities and challenges for manufacturing. Int. J. Res. Eng. Sci. 2016, 4, 30–38.
64. Babu, S.S.; Mourad, A.H.I.; Harib, K.H. Unauthorized usage and cybersecurity risks in additively manufactured composites: Toolpath reconstruction using imaging and machine learning techniques. In Proceedings of the 2022 Advances in Science and Engineering Technology International Conferences, Dubai, United Arab Emirates, 21–24 February 2022; pp. 1–7.

Retrieved from https://encyclopedia.pub/entry/history/show/114719