2023

Strategies Dental Center Leaders Use to Improve Productivity Using Onsite 3D Printing

Edward Zamanian
Walden University

Walden University

College of Management and Human Potential

This is to certify that the doctoral study by

Edward Zamanian

has been found to be complete and satisfactory in all respects,
and that any and all revisions required by
the review committee have been made.

Review Committee
Dr. WooYoung Chung, Committee Chairperson, Doctor of Business Administration Faculty

Dr. Kim Critchlow, Committee Member, Doctor of Business Administration Faculty

Dr. Betsy Macht, University Reviewer, Doctor of Business Administration Faculty

Chief Academic Officer and Provost
Sue Subocz, Ph.D.

Walden University
2023

Abstract

Strategies Dental Center Leaders Use to Improve Productivity Using Onsite 3D Printing

by

Edward Zamanian

MS, Kettering University, 1995

BS, General Motors Institute, 1986

Doctoral Study Submitted in Partial Fulfillment

of the Requirements for the Degree of

Doctor of Business Administration

Walden University

July 2023

Abstract

Many dental centers are leveraging onsite 3D printing to increase their productivity and improve the quality of care they provide. However, dental center leaders lacking strategies to implement onsite 3D printing in their dental centers fail to take advantage of the substantial benefits of using this new technology. Grounded in the theory of disruptive innovation, the purpose of this qualitative multiple-case study was to explore strategies dental center leaders use to improve productivity using onsite 3D printing. The participants comprised five dental center leaders in the United States who successfully implemented strategies to improve productivity using onsite 3D printing. Data were collected from semistructured interviews, company websites, and publicly available information. Thematic analysis was used to analyze the data. Three themes emerged: (a) enabling technology strategy, (b) innovative business model strategy, and (c) customer demand strategy. A key recommendation includes ensuring better patient experiences with less chair time, fewer visits, and more access to care. The implications for positive social change have the potential to make affordable quality dental care available to underserved communities, facilitate new career opportunities for local communities, and contribute to the economic development of these communities.

Strategies Dental Center Leaders Use to Improve Productivity Using Onsite 3D Printing

by

Edward Zamanian

MS, Kettering University, 1996

BS, General Motors Institute, 1986

Doctoral Study Submitted in Partial Fulfillment

of the Requirements for the Degree of

Doctor of Business Administration

Walden University

July 2023

Dedication

First and foremost, I am grateful for our Almighty God who gave me countless blessings during this research study. He granted me perseverance, patience, guidance, and knowledge to complete this study. Most of all, I dedicate this dissertation to my family--my late father, George, my mother, Anahid, my parents-in-law, Yeremia and Marie Jeanne Chaderjian, and my amazing wife, Caroline, as well as my beautiful daughter, Taleen, who were exceptionally inspirational, patient, and understanding throughout my intense academic years. They motivated me to stay on course and complete my research in a timely manner. Without them, my doctorate degree would have been nearly impossible.

Acknowledgments

I sincerely appreciate my esteemed professor Dr. Chung at Walden University for his guidance, stimulating questions, and insightful comments. He was influential in shaping my research paper. He gave me extensive encouragement and many hours of mentoring to bring my research to fruition. Furthermore, I express my gratitude and appreciation to the rest of my colleagues at Walden University for t.ir comments/suggestions. I'm deeply grateful for both committee members and the University Research Reviewer (URR) for their participation and constructive feedback so I could reach my educational goal. I also want to thank all the dental professionals who devoted time away from their busy schedules to participate in my research interviews.

Table of Contents

List of Tables iv

List of Figures v

Section 1: Foundation of the Study...1

Background of the Problem 1

Problem and Purpose 2

Population and Sampling 3

Nature of the Study 3

Research Question 4

Interview Questions 5

Conceptual Framework 5

Operational Definitions..6

Assumptions, Limitations, and Delimitations..6

Assumptions.. 6

Limitations 7

Delimitations... 7

Significance of the Study 7

Contribution to Business Practice 7

Implications for Social Change.. 8

A Review of the Professional and Academic Literature.....................................8

Disruptive Innovation Theory.. 10

3D Printing.. 31

Digital Dentistry 36

Dental 3D Printing 40

Dental 3D Printing Business Impacts 42

3D Dental Printing Challenges 44

Transition 45

Section 2: The Project 47

Purpose Statement 47

Role of the Researcher 47

Participants 50

Research Method and Design 52

Research Method 52

Research Design 54

Population and Sampling 55

Ethical Research 57

Data Collection Instruments 59

Data Collection Technique 61

Data Organization Technique 63

Data Analysis 64

Yin's 5 Step Data Analysis Process 65

Conceptual Software Application Plan 69

Reliability and Validity 70

Reliability 70

Validity 70
Data Saturation 72
Transition and Summary 73
Section 3: Application to Professional Practice and Implications for Change 74
Introduction 74
Presentation of the Findings 76
Theme 1: Enabling Technology Strategy 77
Theme 2: Innovative Business Model Strategy 83
Theme 3: Customer Demand Strategy 85
Connection to Conceptual Framework 91
Connection to Literature 91
Applications to Professional Practice 93
Implications for Social Change 94
Recommendations for Action 95
Recommendations for Further Research 95
Reflections 95
Conclusion 96
References 97
Appendix A: Figure Reprint Permission Letter 117
Appendix B: Invitation Letter 118
Appendix C: Interview Protocol 120

List of Tables

Table 1. Participant Demographic Summary 75

Table 2. Themes Tied to Conceptual Framework 77

List of Figures

Figure 1. Typical 3D Printing Process Flow.. 33

Section 1: Foundation of the Study

3D printing is an innovative production process that builds parts layer by layer directly from computer-aided design (CAD) data (Lee et al., 2021). Users can produce parts with complex geometries in shorter lead times using various materials, including plastics, ceramics, and metals (Rouf et al., 2022). However, 3D printing is also a disruptive innovation that has been embraced by the medical and dental industries (Rouf et al., 2022). Disruptive innovations can change existing business models and force companies to adapt or become obsolete (Christensen, 1997a).

Background of the Problem

3D printing has evolved from a novel break-out technology to a mainstream process used in the medical and dental sectors (Rouf et al., 2022). 3D printing is considered a catalyst for the fourth industrial revolution and has been designated a disruptive innovation (Kulkarni et al., 2021; Öberg & Shams, 2019). Clinicians using 3D printing can fabricate parts based on a patient’s unique physiology, providing a competitive advantage in individual medical and dental treatments (Dennies, 2021). Rekow (2020) stated that 3D printing is an integral part of digital dentistry and was classified as disruptive. One of the significant advantages of dental 3D printing is reduced patient chair time, which increases productivity and reduces operational costs for clinicians in dental clinics (Villias et al., 2022). Nicali et al. (2022) forecasted that dental 3D printing will become the leading source for producing dental restorations worldwide by 2027, surpassing all current production processes. Berman (2020) reported that the dental 3D manufacturing market grew from $780 million per year to over $3.1 billion in

2020. The potential also exists for clinicians to adopt other dental 3D printing applications onsite, such as crowns and other prosthodontic restorations, resulting in increased dental center productivity (Turkyilmaz & Wilkins, 2021). Thus, dental 3D printing represents a paradigm shift in the operation of dental clinics, with onsite capabilities eliminating outside laboratory requirements (Turkyilmaz & Wilkins, 2021). Clinicians who employ onsite dental 3D printing in their practices have the potential to increase productivity while providing a better patient experience (Turkyilmaz & Wilkins, 2021). Interest in 3D printing is evidenced by the exponential increase in the number of peer-reviewed articles published, which expanded from 10 articles in 1986 to 16,082 articles in 2020 (Jemghili et al., 2021). The research trend subset of dental 3D printing also showed a similar exponential growth, with the number of peer-reviewed articles increasing from zero in 2006 to 23 in 2014 and 297 in 2019 (Kihara et al., 2021). However, onsite dental 3D printing requires further research with the continued use of the technology to address challenges regarding improving speed, reducing cost, and expanding the development of dental-specific materials (Alageel, 2022). Furthermore, limited research exists that addresses strategies that dental center leaders use to improve productivity using onsite 3D printing.

Problem and Purpose

The specific business problem is that some dental center leaders lack strategies to improve productivity using onsite 3D printing. The purpose of this qualitative multiple case study was to explore strategies that dental center leaders use to improve productivity using onsite 3D printing. The targeted population consisted of five different dental center leaders located in the United States who have successfully implemented strategies to improve productivity using onsite 3D printing.

Population and Sampling

Data were collected from five dental center leaders located in the United States who have successfully implemented strategies to improve productivity using onsite 3D printing. I collected data by using semistructured interviews with five dental center leaders. I used purposeful sampling to select at least five participants who had a minimum of 5 years of experience as a dental center leader, responsibility for operational decision making, and a minimum of 2 years of clinical experience with 3D printing. In addition to conducting semistructured interviews, I reviewed company websites and publicly available information on dental 3D printing.

Nature of the Study

Researchers use quantitative, mixed method, and qualitative methodologies to conduct studies (Paoletti et al., 2021). Quantitative researchers measure and determine relationships between variables and outcomes through developing and testing hypotheses for examining variables' characteristics, relationships, or group differences to address the research question (Ahmad et al., 2019). Researchers use mixed method to combine characteristics of quantitative and qualitative methods in the same study (Paoletti et al., 2021). I considered quantitative and mixed method research; however, measuring and determining relationships between variables and outcomes through developing and testing hypotheses for examining variables' characteristics, relationships, or group differences would not have helped to address my research question. Qualitative researchers use open-ended questions focusing on the “how,” “what,” or “why” of a phenomenon to discover what is occurring or what has occurred while exploring the underlying meanings and motivations of participants regarding a phenomenon (Yin, 2018). Therefore, I selected the qualitative method because I asked participants *how* or *what* questions to answer my research question.

I considered three research designs for the study: phenomenological, ethnographic, and case study. Researchers using a phenomenological design seek to explore a phenomenon through individuals’ personal meanings and lived experiences (Neubauer et al., 2019). I deemed phenomenological an inappropriate design for my study because I did not explore individual lives or shared lived experiences. Researchers use ethnographic design to explore complex cultural settings, norms, trends, and social systems through long-term engagement by acquiring observational and interview evidence (Andreassen et al., 2020). I did not seek to explore cultural norms; therefore, I deemed ethnographic design inappropriate for my study design. Using a case study design, the researcher explores a contemporary phenomenon in a real-life setting, where the researcher has little or no control over behavioral events, and the main questions are *how, what, or why* questions (Yin, 2018). Hence, I selected a case study design to explore a real-world phenomenon bounded by time and place to understand the context of the phenomenon to answer my research question.

Research Question

What strategies do dental center leaders use to improve productivity using onsite 3D printing?

Interview Questions

1. What strategies do you use to improve productivity with onsite 3D printing?
2. How has your organization implemented strategies to improve productivity using onsite 3D printing?
3. How do you measure the effectiveness of your strategies using onsite 3D printing?
4. How did you achieve productivity improvements with strategies using onsite 3D printing?
5. How did you address the key challenges implementing your strategies to improve productivity using onsite 3D printing?
6. How did you overcome any barriers to implementing your strategies to improve productivity using onsite 3D printing?
7. What additional information would you like to share regarding strategies to improve productivity using onsite 3D printing that was not included in the interview?

Conceptual Framework

The conceptual framework for this study was the theory of disruptive innovation (DIT). Christensen (1997a) first introduced the concept of disruptive innovation and developed DIT by exploring established firm failures due to capitalizing on emerging technologies. Christensen identified three essential components of disruptive innovations in the DIT: (a) an enabling technology, (b) an innovative business model, and (c) consumer demand influence. An enabling technology refers to an innovation that has the potential to cause market disruption by drastically improving the performance or capabilities of products and services. An innovative business model refers to core strategies and business processes that ensure profitability or financial returns from incorporating the enabling technology. Consumer demand influence refers to the mindset to focus on ensuring the adoption of the enabling technology has positive effects on customers' experience and satisfaction. DIT was applicable to this study because the concepts of this theory were suitable for identifying the merging themes in this study.

Operational Definitions

Additive manufacturing: The official term given by the American Society for testing and materials for 3D printing (Lee et al., 2021).

Disruptive innovation: New products or services offered by smaller companies that challenge established incumbent businesses where the innovation originates from either a low-end or new-market foothold (Christensen et al., 2018).

Disruptive technology: A novel technology that initially offers lower performance than existing technologies while extending other advantages, such as less costly, simpler, or greater convenience, that eventually overtakes existing technology (Christensen, 1997a).

Assumptions, Limitations, and Delimitations

Assumptions

Assumptions in a study are facts perceived as truthful that cannot be verified by the researcher (Theofanidis & Fountouki, 2018). The assumptions for this study were that (a) multiple case study design was appropriate, (b) participants possessed the appropriate strategies implementing onsite dental 3D printing to improve productivity, (c) participants were honest and truthful in answering interview questions, and (d) five semistructured interviews and supporting documentation achieved data saturation.

Limitations

Limitations concern potential study weaknesses out of the researcher's control (Theofanidis & Fountouki, 2018). The limitations to the study were that (a) some participants were not willing to participate in this study due to company policies or time constraints, and (b) participant responses to open-ended questions did not provide data that can be used to reach valid conclusions.

Delimitations

Delimitations are boundaries or limits set by the researcher that insure achievement of the study's objectives (Theofanidis & Fountouki, 2018). The boundaries for this study were (a) five dental center leaders located in the United States who had successfully implemented strategies to improve productivity using onsite 3D printing, (b) participants represented five different dental centers in the United States, (c) dental center leaders had a minimum of 5 years in leadership and 2 years of 3D printing experience, and (d) dental centers required at least one onsite 3D printer.

Significance of the Study

Contribution to Business Practice

The results of this study may be of value to dental center leaders pursuing strategies to improve dental center productivity through the implementation of onsite 3D printing. Findings from this study might improve dental center business practices by identifying potential patient throughput improvement using onsite 3D printing. The findings of this study might contribute to effective business practice by providing leaders with strategies that may protect the dental practice from incurring unforeseen 3D printing implementation costs and offer a competitive advantage over competitors.

Implications for Social Change

The results of the study may contribute to a positive social change by reducing the cost of quality dental care to underserved communities and enhancing residents' quality of life in those communities by addressing the long-term issues associated with inadequate dental health. The implementation of onsite dental 3D printing also has the potential to spur new careers to support the expansion of economies of communities served by dental centers.

A Review of the Professional and Academic Literature

The purpose of this qualitative multiple case study was to explore strategies that dental center leaders use to improve productivity using onsite 3D printing. Researchers have given considerable attention in the literature to the evolution of 3D printing as a disruptive innovation impacting traditional business development (Martínez-Vergara & Valls-Pasola, 2020). Digital dentistry, including advanced scanning, imaging, and 3D printing capabilities, may make traditional dental processes more efficient by 2028 (Rekow, 2020). However, the 3D printing aspect of digital dentistry requires additional research, education, a better return on investment, and improved productivity over conventional processes for fabricating dentures, aligners, implants, prosthetics, and guides before widespread implementation is achieved (Akyalcin et al., 2021). The advances in printing technology, materials, and cost reduction of equipment support 3D printing availability to practitioners (Turkyilmaz & Wilkins, 2021). Digital dentistry using 3D printing allows practitioners to create complex geometric forms using ceramic, plastics, and other materials from digital data and may revolutionize dentistry by making procedures less time-consuming and providing better quality care to patients (Chakraborty et al., 2021). However, there is a lack of research concerning the implementation of onsite dental 3D printing and its potential impacts on productivity (Joda et al., 2021; Kessler et al., 2020).

I conducted a comprehensive literature review of existing research using the various databases available from the Walden University Library, including Academic Search Complete, BioMedCentral, EBSCO, ProQuest, PubMed, Science Direct, and SAGE Journals. Additional searches were performed using Google Scholar. Key search terms included d*ental 3D printing, dental additive manufacturing, digital dentistry, 3D printing business impacts, disruptive dental innovation, disruptive innovation theory, diffusion of innovation theory, value chain evolution theory,* and *3D printing disruptive innovation.*

In the literature review, I examined a total of 87 references, of which 74 were articles published between 2018 and 2023, representing 85%. Additionally, the literature review contains 81 peer-reviewed articles, representing 93%. The literature included two nonpeer-reviewed articles and three seminal books, representing 6%. The literature review begins with an introduction and critical analysis of DIT, a critical analysis of DIT tenets, and supporting and contrasting theories. I will continue with an overview of 3D printing and conclude with an evaluation of dental 3D printing.

Disruptive Innovation Theory

The DIT focuses on technologies that brought about disruptions in the marketplace. Christensen (1997a) developed DIT as a theory to address marketplace revolutions driven by companies that adopt disruptive technologies. Some of these technologies have the potential to provide more than marginal or incremental improvements but disrupt markets by entirely replacing existing technologies. Initially, Christensen focused on products considered technological advancements, such as transistors relative to vacuum tubes (as cited in Guo et al., 2019). Compared to existing products, cheaper and simpler products with marginal performance characteristics and attributes insignificant to mainstream customers, such as desktop copiers, are characterized as disruptive technology (Martínez-Vergara & Valls-Pasola, 2020). Christensen's initial disruptive technology studies included the disk drive industry, which experienced multiple disruptions with the continuum shift from 14 inch to 3.5-inch disks, displacing numerous incumbent firms throughout this progression and the change from mechanical to hydraulic excavators.

Companies' approach to emerging markets often determines the impact of disruptive technologies. These disruptive technologies are often commercialized in emerging markets with lower margins, making them unattractive to established firms (Christensen, 1997a). An example is Cisco's development of initially cheaper routers with less voice transmission capability that eventually replaced circuit switching technology (Denning, 2016). Technologies eventually gained dominance in the primary market through continuous improvement, while incumbent firms focused on improving existing product lines and satisfying their most profitable customers (Christensen, 1997a; Martínez-Vergara & Valls-Pasola, 2020).

The definition of DIT has been expanded to include services and business models. DIT initially had not included potential business model impacts (Christensen, 1997a). However, Christensen and Raynor (2003) later expanded the definition of DIT. Christensen and Raynor's broadened view also distinguished between low-end and new-market disruptions (as cited in Martínez-Vergara & Valls-Pasola, 2020). Incumbents ignored the low end of their market while seemingly nonthreatening competitors entered with inferior quality products, such as U.S. automakers dismissing the Japanese introduction of cars to the U.S. market in the late 1950s (Andrews, 2020). Toyota was one disrupter company that steadily improved its offerings until it consumed a significant portion of the incumbents' market (Denning, 2016). A new-market disruption occurs when a group of consumers creates a market where none previously existed (Christensen & Raynor, 2003). For instance, the introduction of the smartphone created an entirely new market and now dominates mobile communication or Amazon, which started as a disrupter to conventional bookstores (Denning, 2016; Martínez-Vergara & Valls-Pasola, 2020).

Disruptive innovation presents opportunities to business leaders who could formulate a business strategy based on their experience with the market. Martínez-Vergara and Valls-Pasola (2020) surmised that disruptive innovation is a process and not an event that may take years or decades to develop. Thus, company leaders can capitalize on disruptive innovation by identifying opportunities early and modifying their business strategy to embrace the impending change (Guo et al., 2019). However, the application of DIT by business leaders does not address decisions involving capital investment, policy formulation, and product development due to the lack of quantitative measurement tools (Guo et al., 2019). Schmidt and Scaringella (2020) supported the concept of using empirical data to link disruptive innovation, organizational capabilities, and business models to develop successful strategies.

Previous Studies Using DIT

Since its introduction, DIT has been widely applied to address the technology, management, and business model aspects of various innovations. In particular, after 2013, there has been a significant upward trend in the number of published works related to DIT, indicating increasing interest, development, and debate of DIT (Si & Chen, 2020). Si and Chen (2020) concluded that DIT is applicable to future studies related to innovation disruptions.

DIT applies to exploring the low-end or new-market perspective of technologies. For example, McDowall (2018) applied the DIT aspects of low-end and new-market concepts to low-carbon transitional technologies. The author concluded that Christensen’s theory is relevant for capturing a specific phenomenon’s dynamics, but the focus was too narrow to capture the broader impact of energy transition (McDowall, 2018). Similarly, Dogru et al. (2019) used DIT to analyze the magnitude of Airbnb’s impact on key hotel markets. Using DIT, the authors classified Airbnb as a disruptive innovation with Airbnb entering the low-end of the market and eventually maturing to compete with mainstream hotels; they found that Airbnb had a significant negative impact on mainstream hotel performance (Dogru et al., 2019).

DIT is also applicable to exploring the global significance of disruptive innovation. Yu et al. (2022) studied startup companies' performance by their networking capabilities in China. The authors used DIT to classify low-end and new-market disruption successes through homogeneous and heterogeneous networks (Yu et al., 2022). Yu et al. found that startups using homogeneous and heterogeneous networks with disruptive innovations positively affected their growth. Moreover, Wang et al. (2022) studied one Chinese company's approach to business model innovation from the perspective of DIT. The authors used DIT to study the firm's approaches to their business strategies and expanded the interpretation with additional guidelines to aid firms' approaches to address innovations (Wang et al., 2022). Wang et al. concluded that business model innovators faced challenges due to the unpredictable operating environment impacted by the information technology revolution, causing shortened time to make decisions and ambiguity of when to execute business model changes. In addition, Sadiq et al. (2020) studied managers' approaches to disruptions and examined the validity of DIT. Sadiq et al. performed the study in Pakistan and matched participants' interview responses to DIT. The authors concluded the successful implementation of disruptive innovations requires different levels of managerial support through the phases of product development (Sadiq et al., 2020).

DIT can also be useful for assessing and analyzing the impact of digital technology. For instance, Si et al. (2022) used DIT as one of the perspectives to analyze the social and economic impacts of digital technology in emerging and mature countries. Si et al. also used DIT to show how digital technology and disruptive innovation mutually reinforce each other when applied to markets. They concluded that digital technology is disruptive, changing every aspect of industry and society with examples like automated car parking, voice controls, and car to mobile phone connections. Similarly, Thakur et al. (2023) conducted a study in the United States related to digital disruptions from a manager's perspective. Thakur et al. found that digital disruption improved firms' performance and user experience when technology convergence was combined with intelligence, executive-level support, and innovation embedded in the corporate culture. Additionally, Anggasta and Kusumawardhani (2021) analyzed one Indonesian construction company's business strategy to address disruptive innovations. The authors classified digital disruptions using DIT and measured the company's financial and nonfinancial metrics in implementing strategies to address the disruptions (Anggasta & Kusumawardhani, 2021). Anggasta and Kusumawardhani found that the business strategy to address disruptive innovations resulted in an increase in revenue and operating profit from 2018 to 2019 while also improving nonfinancial metrics, such as responsiveness to dynamic markets, improvement in organizational learning, and life cycle improvement of the firm.

DIT and 3D Printing

Authors of several studies have examined the 3D printing phenomenon to see if the technology should be classified as disruptive according to DIT. For example, Öberg and Shams (2019) studied the metal 3D printing industry and concluded that 3D was a disruptive innovation and impacted firms by a different magnitude depending on their role as subsuppliers, manufacturers, or logistics firms. Likewise, Beltagui et al. (2020) traced the evolution of 3D printing from its origins to its current state. Beltagui et al. concluded that 3D printing disrupts existing business strategies and firms need to repurpose capabilities advocating new technologies such as 3D printing. Moreover, Kilkki et al. (2018) studied the impact of 3D printing on specific sectors of industry. Kilkki et al. concluded that 3D printing has the potential to disrupt the supply chain sector. Finally, Steenhuis and Pretorius (2017) studied the impact of 3D printing across multiple industries and whether 3D printing should be classified as an incremental change or a disrupter that could start another industrial revolution. Steenhuis and Pretorius concluded the disruptive impacts of 3D printing depend on the industry affected.

Disruptive Innovation Theory Tenets

Companies Depend on Customers and Investors for Resources. How companies invest is influenced by several factors. One of these factors is customer influence. Companies' investment patterns focus on satisfying customers (Christensen, 1997a). The revenues provided by customers influence how firms invest in future technologies (Christensen, 1997a). Pérez et al. (2017) also supported the concept of customer influence on investments using the example of how customers historically funded the space industry's major research and development projects.

However, there are risks associated with following historical investment patterns. Managers who focus their resources on providing products that satisfy their most influential customers risk losing a leadership position in the market when disruptive innovations are ignored (Martínez-Vergara & Valls-Pasola, 2020). Deep-rooted views on business investments based on experiences influence a company's leadership to focus their resources on current customers and miss disruptive innovation opportunities (Si & Chen, 2020). Christensen (1997a) summarized how customers exert extraordinary influence on where companies invest money by following customer desires, analyzing market size, and forecasting the profitability of investments. Likewise, Steenhuis and Pretorius (2017) and Kilkki et al. (2018) reiterated the concept of companies relying on their most demanding and profitable current customer needs to guide their investment strategy and the danger of incumbents missing the opportunity to invest in novel technologies that disrupt the market.

Companies could fail when they did not adjust business strategies to adopt disruptive innovations. One example is Kodak, which ignored the digital photography revolution and continued focus on print photography (Kilkki et al., 2018). Kodak's management actions resulted in the business filing for bankruptcy in 2012 (Kilkki et al., 2018). Incumbent companies can struggle to dedicate research and development resources to disruptive innovations due to commitments to existing business models and customers (Si & Chen, 2020). However, incumbent firms' success or failure depends on the intuition and competence of their leaders when dedicating the organizations' resources (Sadiq et al., 2020). Thus, the ambiguity of predicting disruptive innovation's revenues and costs does not fit the typical business plan decision process for dedicating resources (Martínez-Vergara & Valls-Pasola, 2020).

Creating a separate autonomous organization could enable firms to embrace disruptive innovations. However, O'Reilly and Binns (2019) provided a counterargument to the tenet that autonomous organizations are required to develop disruptive innovations successfully. Some examples of companies pursuing alternative approaches to addressing disruptive innovations include General Motors investing in startups to access new technology for autonomous cars, Ford using hackathons to encourage creativity, General Electric implementing lean startup programs, and open-source innovation used by Samsung to develop new ideas (Martínez-Vergara & Valls-Pasola, 2020; O'Reilly & Binns, 2019).

Small Markets Do Not Solve the Growth Needs of Large Companies. How large companies address market size influences strategy decisions. Large organizations often allocate financial and human resources through formal and informal processes to larger markets based on the assumption that smaller emerging markets do not provide sufficient growth opportunities (Christensen, 1997a). Furthermore, companies that base their business models on higher volumes and lower costs with the goal of maximizing shareholder value and company profits often do not pursue smaller emerging markets due to uncertainty over the revenues and profits associated with disruptive innovations (Martínez-Vergara & Valls-Pasola, 2020). Companies have historically achieved higher profit margins by serving their mainstream customers with products and services that were incrementally improved while ignoring potential disruptions (Christensen et al., 2018). Thus, established firms' investments in new innovations are constrained due to existing profit models that focus on existing customers and drive incumbents to ignore disruptive innovations that typically forecast lower margins and smaller markets with inferior products and services that do not appeal to existing customers (Christensen et al., 2018; Si & Chen, 2020).

However, contrary to Christensen's tenet, there are examples of incumbent companies that were able to enter smaller markets while successfully fueling future growth. For example, telephone landline companies that successfully entered the mobile phone market or Goodyear retooling to produce radial tires (Ho, 2021; Sampere et al., 2016).

There are risks and opportunities associated with smaller markets. Companies ignoring small markets make them susceptible to losing market share and being disrupted (Christensen, 1997a). Companies that enter emerging markets early have the advantage over later entrants by establishing connections with customers they keep while improving their products (Christensen et al., 2018). To take advantage of smaller emerging markets, companies require flexible business models that account for customers and incumbents unwilling to change by predicting which future products or services will impact a business sector (Martínez-Vergara & Valls-Pasola, 2020).

There are strategies companies could follow to address disruptive innovations. The impact of predicting these disruptive innovations should drive companies to ignore existing customers and invest in products or services that offer lower performance and lower margins while pursuing smaller markets (Martínez-Vergara & Valls-Pasola, 2020). Large companies that are successful in implementing disruptive innovations follow a dual strategy where they compete in existing markets through incremental improvements while they pursue new technologies and markets (O'Reilly & Binns, 2019). The emergence of open access journals provides an example of a flexible business model that distributes free journals to readers with the costs incurred by the author or institution (Kumaraswamy et al., 2018).

There are other factors that impact companies due to disruptions. Firms that allocated resources to smaller emerging markets failed due to existing forces within the organization that favored supporting traditional markets (Christensen et al., 2018). Sampere et al., (2016) argued that incumbents may not be impacted due to the amount of time it takes for disruptions to impact different industries such as retail which may take decades to evolve. Also, Sampere et al., (2016) pointed out that disruption may only affect one business unit in an entire company and researchers require diligence when evaluating business impacts due to disruptions. Firms that allocated resources to smaller emerging markets failed due to existing forces within the organization that favored supporting traditional markets (Christensen et al., 2018).

Here is one example of a large company that did not fail at addressing smaller markets. Contrary to Christensen's tenet, IBM is a large company with a flexible business model that successfully addressed smaller markets (Beltagui et al., 2020). IBM set up and shut down separate business units focused on specific markets (Denning, 2016). IBM's success was achieved by controlling resources allocated to the individual business units as the markets for the products and services increased or decreased (Denning, 2016).

Markets That Do Not Exist Cannot Be Analyzed. Companies follow established processes for analyzing markets but may not be relevant for disruptive innovations. The characteristics of sound management require planning with detailed market research before launching new products (Christensen, 1997a). In the case of disruptive innovation, thorough market research provided by marketing professionals before a new product or service justification does not work (Christensen, 1997a). The reason is the market and financial data do not exist, paralyzing firms or causing them to make mistakes (Christensen et al., 2018). Industry incumbents face challenges when dealing with disruptive innovation due to the incompatibility with established business models that require detailed market analysis prior to dedicating resources to a project (Martínez-Vergara & Valls-Pasola, 2020; Schmidt & van der Sijde, 2022). Established firms' decision-making processes rely on precise data and accurate predictions of the potential market for the new product or service (Martínez-Vergara & Valls-Pasola, 2020).

There are examples of established market analysis that failed. One example occurred in the disk drive industry. Incumbent firms focused on the capacity of the disks rather than the physical size based on existing customer requirements (Ho, 2021). According to Ho (2021), these firms failed because they applied standard market forecasting processes and missed groups of users and market segments that used different sizes of disk drives to equip computers in new market segments that did not exist until the personal computer market began to expand. Another example is when established United

States motorcycle manufacturers failed to address a market segment. Honda's success in the United States stemmed from the accidental creation of a new market segment for small off-road motorcycles which no other motorcycle manufacturer could analyze because the market previously did not exist (Christensen, 1997a).

There are firms that have implemented strategies to address markets that do not exist. Christensen et al. (2018) stated firms require strategies to analyze markets that do not exist to successfully implement disruptive innovations. According to O'Reilly and Binns (2019), there are methods that successful firms use to analyze markets that do not exist.

One example of a firm addressing nonexistent markets is Amazon which employs a process to predict market opportunities without using standard analysis tools. Amazon leverages people closest to problems since they are the best source for solutions (O'Reilly & Binns, 2019). Amazon's employees focus on long-term thinking rather than short-term profits when analyzing innovations recognizing that returns on capital investments may not occur for years (Thakur et al., 2023). Amazon's leadership acknowledges that failure and invention are closely related while encouraging a passion for innovation through patience and persistence (O'Reilly & Binns, 2019). Amazon employees follow a structured process when presenting new ideas to company leadership that includes a hypothetical press release of the new product with a backup document of frequently asked questions that elaborate on why customers want the product, cost, benefits, potential market size, and risks associated with the new product or service (O'Reilly & Binns, 2019; Thakur et al., 2023).

The use of hybrid offerings is another example of addressing nonexistent markets. Christensen et al. (2018) also suggested a method for addressing nonexistent markets using hybrid offerings. Hybrid offerings combine features of existing offerings with future innovations that provide incumbents with the ability to improve existing products while learning and adapting to new technologies (Christensen et al., 2018). McDowall (2018) used the example of the automotive transition from electric hybrid automobiles to fully electric vehicles, where incumbents were able to maintain leadership in existing markets while developing the new technology.

Companies may also use value networks and the capabilities approach to address nonexistent markets. Yu et al. (2022) identified value networks and the capabilities approach to address markets that do not exist. Incumbents use the outside-in capabilities approach by engaging external organizations to sense markets separate from mainstream customers (Pérez et al., 2017). Pérez et al. (2017) used the space industry as an example of new market potential. Google and other Silicon Valley companies provide opportunities away from traditional customers such as TV providers to use space for new data streams and space-based internet (Pérez et al., 2017; Yu et al., 2022).

An Organization's Capabilities Define Its Disabilities. Organizational capabilities comprise several aspects of a company. Organizational capability resides in its processes and values (Christensen, 1997a). Transforming inputs such as labor, materials, cash, and technology into higher-value outputs characterizes organizational processes (Christensen et al., 2018). Christensen defined organizational values as the criteria leadership uses to prioritize business decisions. These capabilities define the strength of an organization when generating profits in its core business (Christensen, 1997a).

Organizational capabilities could also be a weakness in the realm of disruptive innovations. When pursuing new opportunities with disruptive potential, organizational strengths become an organization's weakness (O'Reilly & Binns, 2019). Incumbent firms focus their capabilities on existing customers and markets for future growth while ignoring disruptive innovations due to limited resources already assigned to mainstream projects and the difficulty in predicting potential gains for disruptive innovations (Sadiq et al., 2020). This focus becomes an organization's disability when senior managers hesitate to concentrate their capabilities on potential new businesses that will take assets and capabilities from existing profitable businesses and dedicate them to projects with uncertain or lower margins (O'Reilly & Binns, 2019). The processes and values that defined the successful capabilities of firms in the context of existing business also explained their disabilities in the context of disruptive innovation (Christensen, 1997a).

There are strategies organizations could follow to address disabilities related to disruptive innovations. Christensen (1997a) stated organizations require strategies to address organizational disabilities to enable the development of disruptive innovations. Christensen proposed that creating an autonomous business unit that operates independently from the core business is one method for addressing an organization's disabilities. IBM provides an example of implementing this strategy when it set up a separate independent business unit to survive in the growing market for personal computers that were not restricted by standard company policies (Denning, 2016).

However, CISCO failed in its attempt to create an autonomous business unit due to its inability to use a disciplined process when scaling new ventures (O'Reilly & Binns, 2019).

Organizations could also employ an ambidextrous approach to business strategies for disruptive innovations. Counter to Christensen's original concept of autonomous business units involves ambidextrous organizations (Christensen et al., 2018). Christensen et al. (2018) described ambidextrous organizations following different innovations separately while having flexible executive leadership that manages conflicts between the dual structures, processes, and subcultures. O'Reilly and Binns (2019) proposed that creating ambidextrous organizations addresses organizational disabilities allowing incumbent firms to pursue potential disruptive innovation. USA Today provided an example of a successful ambidextrous organization by adding web and television to its print platform (O'Reilly & Binns, 2019). General Motors created an ambidextrous organization to develop autonomous vehicles and ridesharing parallel to mainstream businesses (O'Reilly & Binns, 2019).

Technology Supply May Not Equal Market Demand. Technology development could be disabling depending on relation to market demand. When technology development surpasses consumer demand, the functionality and features may overperform customer requirements (Christensen, 1997a). Companies with products that serve mainstream customer needs will continue improving until they overshoot future customer requirements (Christensen, 1997a). Incumbents that develop more advanced products with features beyond consumer needs overserve the market (Christensen et al., 2018).

When a company supplies technology beyond consumer demand, there could be negative consequences. Christensen (1997a) used the term "performance oversupply" to describe the condition when technology exceeds the needs of the mainstream market. Christensen (1997b) used the worldwide insulin business as an example of performance oversupply. Eli Lilly and Company improved insulin impurities extracted from cow and pig pancreas from 50,000 parts per million in 1925 to ten parts per million in 1980 (Christensen, 1997b). Eli Lilly invested nearly a billion dollars in developing a 100 percent pure synthetic insulin and introduced Humulin 19 to the market at a 25 percent premium over animal extracted insulin in the early 1980s (Christensen, 1997b). Only a fraction of the population required the pure insulin and Humulin 19 failed in the market because most users were not dissatisfied with the animal-derived insulin, which shows how the performance trajectory of the new product overshot the market need (Christensen, 1997b).

Higher profit products could have a negative impact on customers and also produce an opportunity for new product entrants. As incumbent companies produce products and services that generate higher profitability, they overshoot the needs of low-end and many mainstream customers (Christensen et al., 2018). The gap created at the bottom of the market between customer needs and product performance provides an opportunity for new market entrants (Christensen et al., 2018). New products with technological performance that meets customer demand may have lower performance than the high-end incumbent products but create the opportunity for disruptive innovation (Ho, 2021). The incumbents are lulled into thinking the lower performance will not appeal to mainstream customers and focus on improving the existing technology (Christensen et al., 2018). One example is Cisco's development of initially cheaper routers with less voice transmission capability that ultimately replaced circuit switching technology (Denning, 2016). The incumbent Lucent listened to existing customers and continued the development of circuit switching technology, which was initially better than router technology for voice transmission, eventually losing the market to Cisco (Denning, 2016).

There are examples that do not follow Christensen's technology supply and demand perspective. Schmidt and van der Sijde (2022) proposed a different perspective on technology supply and market demand. The authors segmented different disruptive innovation business models into archetypes (Schmidt & van der Sijde, 2022). The matchmaker archetype aligns supply with demand, thus avoiding overserving or underserving customers (Schmidt & van der Sijde, 2022). Sadiq et al. (2020) used the examples of mobile payment platforms that enable peer-to-peer transactions and patients matched to clinicians for specific treatments as matchmaker archetypes.

Complementary and Contrasting Theories

Theory of Creative Destruction. There are existing theories that support DIT. In one example, Schumpeter (1942) developed the theory of creative destruction, which is a supporting theory of DIT. Schumpeter's theory helped to address new innovations that revolutionize manufacturing processes within an industry. These innovations transform the industry's economic structure while destroying the existing system (Schumpeter, 1942). These creative and destructive processes are entrenched in a capitalist society and are a primary driver of business practices (Ho, 2021). The evolutionary nature of creative destruction is essential in creating new products, processes, and markets (Schumpeter, 1942). Schumpeter described the three characteristics of economic development through creative destruction as occurring from within an economic system, not occurring smoothly, and creating radically new conditions while destroying existing conditions.

A theory could support different impacts on industry depending on its focus. Schumpeter's theory of creative destruction focused on the capitalistic macroeconomics of an industry (Ho, 2021; Komlos, 2016). Komlos (2016) surmised that Schumpeter developed this theory based on changes due to the first and second industrial revolutions, including steam engines, electrification, telephones, automobiles, airplanes, and machines. These changes enhanced overall public welfare while the destructive impacts were minimal (Ho, 2021; Komlos, 2016).

Innovation has impacts on competition. According to Spencer and Kirchhoff (2006), innovation provides the primary driver for competition rather than price in creative destruction. One example is the evolution of the personal computer industry where industry-leading firms such as Control Data, UNIVAC, and Prime Computer were destroyed with the emergence of Apple, Dell, Gateway, and HP-Compaq (Spencer & Kirchhoff, 2006).

There are instances where change has minimal impact on consumers. One example that does not follow the Schumpeterian theory where changes do not result in a value increase for consumers is the process of planned obsolescence (Ho, 2021; Komlos, 2016). Planned obsolescence in video games, software, cell phones, and consumer electronics only produces minor product improvements while forcing consumers to upgrade with minimal added value to the consumer (Ho, 2021; Komlos, 2016).

There are different levels of economic growth driven by innovation. Schumpeter (1942) and Christensen (1997a) agreed that innovation drives economic growth. Schumpeter focused on a macroeconomic or industry-level impact, whereas Christensen focused on a microeconomic or firm-level impact. Schumpeter provided the precursor to Christensen's development of DIT (Christensen, 1997a). Schumpeter identified innovation as the key to creative destruction, and Christensen identified innovation as the key to disruption. Christensen (1997a) identified disruptive technology as a cause of Schumpeter's creative destruction. Christensen and Schumpeter acknowledged that accurate data does not exist when making business decisions related to innovations. Each author acknowledged the importance of investors, entrepreneurs, management, and types of organization when pursuing innovations. Christensen focused on company profits and firm survival while providing specific examples of disruptive innovation, counter to Schumpeter, who focused on macroeconomics and did not provide specific examples of creative destruction.

Diffusion of Innovation Theory. There are examples of contrasting theories to DIT. One example is Rogers (1995) diffusion of innovation theory. Diffusion of innovation theory is a contrasting theory to DIT. Rogers's theory, which originated in

1962, involves the communication of an innovation among members of a social system over time (Dearing & Cox, 2018).

Rogers (1995) described stages and adopter categories detailing the innovation implementation process over a period. Rogers provided social system member classification based on innovativeness, including innovators, early adopters, early majority, late majority, and laggards. When plotted relative to a time frame, a normal distribution is formed with innovators comprising 2.5% of the population, early adopters at 13.5%, early majority at 34%, late majority at 34%, and laggards at 16% (Millar et al., 2018). The differences between category members can be attributed to socioeconomic status, personality variables, and communication behavior enabling population segmentation (Rogers, 1995). Ho (2021) provided a further description of category members' attributes. Innovators are first users, new idea lovers, and risk-takers (Ho, 2021). Early adopters realize a need for change, love new ideas, and are opportunists (Ho, 2021). The early majority seek evidence, while the late majority are followers, and the laggards desire to preserve traditions (Ho, 2021).

Theorists originate theories from different perspectives. Rogers' (1995) theory originated from a sociological and not a technical perspective which differs from DIT (Beausoleil, 2018). According to Beausoleil, Rogers focused on human and systemic processes while adopting innovative processes, products, or new technologies. Rogers' original model focused on individual innovation diffusion. Researchers applied the theory to study organizations which Rogers viewed as problematic because of the differences between individuals and organizations (Lund et al., 2020).

Differences between organizations and individuals could impact technology adoption. One example is from a Colombian study conducted between 1963 to 1970, where Havens and Flinn (1975) analyzed coffee productivity improvements through the diffusion of new technologies such as new coffee varieties, fertilizers, and weedicides. Havens and Finn observed that 17 of the original 64 organizations successfully adopted the new technologies due to the ability to borrow money which permitted a subgroup to acquire financing to bridge the initial losses in the beginning years. The resulting failures were not due to diffusion through adopter groups but because of systemic issues with the ability to receive financial assistance (Goss, 1979).

There are fundamental differences between the focus of DIT and diffusion of innovation theory. Christensen's DIT focused on firm or organizational level differing from Rogers' diffusion of innovation theory which focused on individuals as part of an organization. (Ho, 2021). Innovation diffusion involves high-end innovation with superior performance and higher costs than existing products (Ho, 2021). The early innovators and adopters have the financial resources to take risks, followed by other social system members, if the innovation can bridge the gap to the early majority (Ho, 2021). Christensen's (1997a) DIT differs from innovation diffusion in this regard where products enter the low-end of the market with marginal performance and are initially disregarded by incumbent firms. Ho (2021) stated electric cars and mobile phones are examples of high-end and high-performance innovations introduced at a higher cost than existing products which fits diffusion of innovation theory and not DIT.

3D Printing

The history of 3D printing followed an evolutionary path. The 3D printing process is also known as additive manufacturing, rapid manufacturing, rapid prototyping, and direct digital manufacturing (Kulkarni et al., 2021). C. Hull developed the process in 1987 (Abdulhameed et al., 2019). Over the years, 3D printing has evolved with the introduction of different types of printers and printing processes (Rouf et al., 2022). These printers are capable of producing parts with a multitude of different materials such as plastics, ceramics, and metals while becoming more affordable with usage in the automotive, aerospace, engineering, construction, military, fashion, architecture, and medical industries (Rouf et al., 2022).

There has been a growing interest and expansion in the 3D printing market. The expiration of 3D printing patents has made these printers more affordable and expanded customers’ access to the technology (Fan et al., 2020). In 2018, the overall 3D printing market was $9.9 billion and is expected to reach $34.8 billion by 2024 (Fan et al., 2020). Interest in 3D printing is evidenced by the exponential increase in the number of peer-reviewed articles published which expanded from 10 articles in 1986 to 16,082 articles in 2020 (Jemghili et al., 2021).

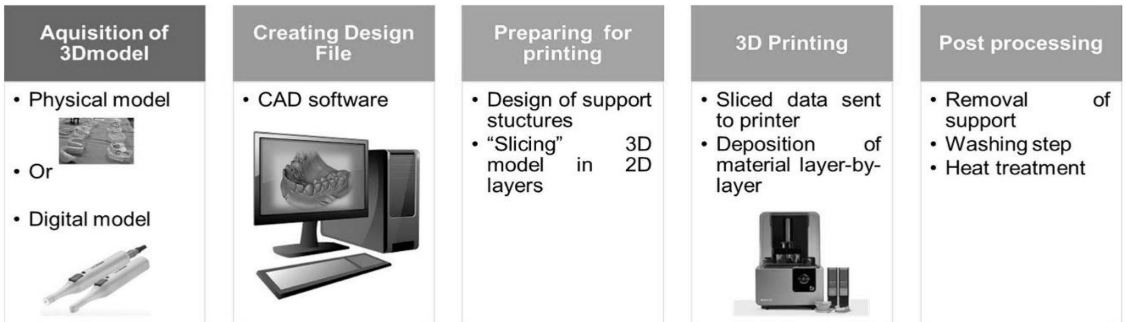
The expansion of 3D printing has implications beyond manufacturing. Expansion of 3D printing is integral to the emergence of industry 4.0, which includes intelligent automation with the integration between the digital and physical worlds (Abdulhameed et al., 2019; Kulkarni et al., 2021). 3D printing has also been designated as a catalyst for the fourth industrial revolution with the potential to create new business models while changing the work environment especially impacting supply chains with point-of-use manufacturing (Kleer & Piller, 2019; Kulkarni et al., 2021).

There are limiting factors in the implementation of 3D printing. 3D printing still requires development in the areas of part strength, dimensional accuracy, and high-volume production to achieve mainstream implementation (Abdulhameed et al., 2019; Delic & Eyers, 2020). 3D printing challenges remain in product design, materials, machines, supply chain, and business case strategies where firms decide to invest in onsite manufacturing capabilities eliminating supply chain bottlenecks (Abdulhameed et al., 2019; Delic & Eyers, 2020).

Producing parts with 3D printing follows a flow of information to manufacturing. 3D printing uses 3D computer data to build parts by additively depositing incremental layer upon layer of material to produce the final geometry (Maresch & Gartner, 2020). The 3D computer data is either generated by a designer using CAD modeling software or reverse engineered from data obtained from a scanning device such as an intraoral scanner used in dentistry (Kleer & Piller, 2019). The raw materials used in 3D printing start as powders, liquids, or sheet materials and can be metallic, polymer, or ceramic (Kleer & Piller, 2019; Lee et al., 2021). Single-step 3D printing produces parts from a single material and does not require post-processing (Lee et al., 2021). Multiple-step 3D printing combines multiple materials and requires secondary processing (Lee et al., 2021). Figure 1 illustrates the typical process flow for 3D printing.

Figure 1

Typical 3D Printing Process Flow



Note. Process flow may vary for specific 3D printing processes. From "Additive manufacturing of ceramics for dental applications: A review," by R. Galante, C. G. Figueiredo-Pina, and A. P. Serro, 2019, *Dental Materials, 35*(6), p. 831 (https://doi.org/10.1016/j.dental.2019.02.026). Copyright 2019 by Elsevier. Reprinted with permission. See Appendix A.

Seven different types of 3D printing have been classified as material extrusion, material jetting, binder jetting, sheet lamination, directed energy deposition, powder bed fusion, and vat photopolymerization using heat, light, or laser energy to create objects (Delic et al., 2019; Khalid & Peng, 2021). Material extrusion is where the material is dispensed through a nozzle and can produce metal or composite parts such as splints, implants, and tools (Salmi, 2021). Material jetting is where droplets of material are selectively deposited on a build platform moving in the Z direction and is suitable for high accuracy products such as medical models (Alageel, 2022; Salmi, 2021). Binder jetting is where a liquid bonding agent is selectively deposited on a powder bed that moves in the Z direction to create parts and is useful for prototyping since the parts lack strength between the bonded layers (Alageel, 2022; Rouf et al., 2022). Sheet lamination is the process where multiple sheets of material are bonded together and then laser cut to produce the final part (Rouf et al., 2022). Sheet lamination is used to produce metallic parts such as tools or instruments (Rouf et al., 2022). Directed energy deposition uses focused thermal energy to fuse metals by melting when depositing and is suitable for creating machine repair parts (Salmi, 2021). Powder bed fusion uses lasers to selectively fuse granules of powder in layers and is suitable for aerospace and dental applications (Rouf et al., 2022). Vat photopolymerization is where a liquid photopolymer in a vat is cured with light and an example of usage is creating molds for clear orthodontic aligners (Salmi, 2021).

Direct 3D printing final parts may not be possible due to limitations. The limitations in the 3D printing processes can be overcome by combining conventional manufacturing processes, such as machining, with 3D printing, a concept called hybrid manufacturing (Abdulhameed et al., 2019; Delic & Eyers, 2020). Hybrid processing overcomes the limitations of individual processes and provides benefits such as improved dimensional accuracy, improved tool life, and production time reduction (Abdulhameed et al., 2019).

There are significant benefits associated with 3D printing and its applications. Benefits associated with 3D printing have been noted since its inception (Abdulhameed et al., 2019). Manufacturing with 3D printing eliminates fixturing and tooling required in conventional processes leading to cost reductions and shorter lead times while allowing the flexibility to produce complex geometries without constraints (Abdulhameed et al., 2019; Rouf et al., 2022). These attributes of 3D printing make it suitable for low volume production of highly complex parts that enable product customization to support individual customer requirements (Abdulhameed et al., 2019; Ding et al., 2021). Other benefits include energy optimization and waste reduction with material recycling (Kulkarni et al., 2021; Rouf et al., 2022). In the aerospace industry, 3D printing decreased product lead time from 30% to 70%, reduced non-recurring product costs by 45%, and a 30% to 35% reduction in low volume manufacturing costs (Abdulhameed et al., 2019). Abdulhameed et al. stated the medical industry shows great potential for 3D printing applications by producing individual anatomic models for surgery planning, custom orthoses for specific patient anatomies, and the potential for bio-engineered implants.

There are limitations also associated with 3D printing. Some limitations of 3D printing still hinder implementation in mainstream applications including the high cost and a limited material selection available in forms compatible with printers such as ceramics and metals (Abdulhameed et al., 2019; Delic & Eyers, 2020). Other manufacturing limitations include part size restrictions, inferior surface quality, poor accuracy of finished parts, minimal production volumes, and government regulation especially for biomaterials used in medical applications (Abdulhameed et al., 2019; Aimar et al., 2019; Delic & Eyers, 2020). Most of current 3D printing applications are limited to prototyping, tooling, fixtures, and research with only 28.4% of 3D printing output attributed to functional end-use products (Delic & Eyers, 2020).

Digital Dentistry

Digital dentistry has impacted the dental industry with a variety of technologies that affected workflow. The implementation of digital dentistry began in 1980 and refers to dentists' adoption of imaging technologies, computer-aided design/computer-aided manufacturing (CAD/CAM) systems along with practice and patient management systems (Kihara et al., 2021; Shaikh et al., 2021). Dentists that use digital dentistry follow a digital workflow process (Kihara et al., 2021). The digital workflow process starts with image acquisition (Cunha et al., 2021). The image data is then reviewed and manipulated in CAD to feed a specific CAM system that produces the final product (Cunha et al., 2021). Bentson and Copple (2022) described practice management software such as the Gaidge solution used for storing patient demographic information, appointment scheduling, tracking, and billing parallel with keeping electronic patient records and digital images. Digital dentistry has impacted how dentists approach patient care by providing a more efficient workflow while improving the patient experience (Rekow, 2020). Dentists' use of digital processes provided more accurate and precise results when fabricating models or prostheses in the lab or clinic (Schweiger et al., 2021). However, the high cost and complexity of the equipment presented a challenge for dental center implementation (Tian et al., 2021).

Digital Imaging

Digital imaging played an important role in digital dentistry. The use of digital imaging technology transformed dental image capturing from 2-dimensional x-rays to 3-dimensional electronic images (Francisco et al., 2022). Traditional analog techniques also involved physical impression models, which caused patient discomfort and were difficult to store (Pillai et al., 2021). New solutions for dental treatment are created with the integration of intraoral scanning systems into the digital dental workflow (Róth, et al., 2022). Digital imaging techniques provide math data models that can be easily viewed, manipulated, and stored (Pillai et al., 2021). However, original scans are subject to user expertise and can result in inaccurate images (Pillai et al., 2021).

There are limitations and post processing required for digital images. The digital images captured required data manipulation in CAD before being produced (Turkyilmaz & Wilkins, 2021). A human manipulates the data by converting the files to standard tessellation language (STL) and uploading them to 3-dimensional modeling software where the images are modified to meet the clinicians' needs (Turkyilmaz & Wilkins, 2021). Once modified, the data is uploaded to the manufacturing system for part production (Turkyilmaz & Wilkins, 2021). Unfortunately, a lack of expertise exists among dentists and dental technicians in converting and manipulating image data (Rekow, 2020). Rekow also identified data compatibility issues between the different systems that required user interaction. Data compatibility issues are addressed by open architecture systems where the user links data from different components and manufacturers for seamless processing (Rekow, 2020). Rekow noted that these open architecture systems were still under development and required constant renewing with system hardware and software updates.

CAM

CAM is used in dentistry to produce dental objects. The three different dental CAD/CAM production concepts are chairside production, laboratory production, or a centralized production center (Demiralp et al., 2021). Chairside production refers to producing objects in the dental office, whereas laboratory production refers to producing objects at a local laboratory, and centralized production serves as a regional production center (Demiralp et al., 2021; Kessler et al., 2020).

There are two types of dental CAM systems. The original CAM production systems were classified as subtractive manufacturing and used computer numeric controlled (CNC) milling machines to produce parts (Demiralp et al., 2021). Subtractive manufacturing is currently the most widely used CAM system in dentistry (Demiralp et al., 2021). Subtractive manufacturing is achieved by sending the CAD file to a CNC milling machine, where a block of homogeneous material is machined to match the math data (Demiralp et al., 2021). The object is created from a blank through multiple processes including milling, grinding, drilling, turning, and polishing depending on final product requirements (Kessler et al., 2020). Metals, resins, and ceramics are materials used to produce dental products in subtractive manufacturing (Demiralp et al., 2021). Many dental clinics utilize chairside subtractive manufacturing to make crowns and inlays (Kessler et al., 2020). The advantages of subtractive manufacturing include accuracy and proven materials with the required physical and biological attributes for use in dentistry (Kessler et al., 2020). However, subtractive manufacturing can produce up to 90% material waste in the machining process, has a limited surface resolution due to tool radius dimensions, cracks in the final product due to wear from repeated tool usage, and limited flexibility to produce complex geometries (Kessler et al., 2020).

The newer CAM systems use 3D printing. An alternative CAM to conventional subtractive machining in dentistry is 3D printing which uses additive processes to produce objects (Pillai et al., 2021). Dental 3D printing can produce complex geometries more efficiently with superior material utilization compared to subtractive manufacturing (Prasad et al., 2018). Chiu and Chen (2022) stated that 3D printing had been applied to dentistry since the late 1990s with high expectations for widespread implementation which have yet to be realized. CAD advancements and enhanced imaging technologies parallel the rise in dental 3D printing (Pillai et al., 2021). Digital dentistry impacts from 3D dental printing can potentially change future dental processes (Shaikh et al., 2021).

The adoption of digital dentistry is an evolutionary process. Dentists' adoption of digital dentistry continues to evolve in parallel with technological advancements (Rekow, 2020). Creating digital patients enables dentists to design patients' smiles onscreen for treatment planning and better communication of the final esthetic results (Rekow, 2020). Some challenges continue to limit the adoption of digital dentistry including the shortage of skilled workers and the high cost of purchasing and maintaining the equipment (Cunha et al., 2021; Schweiger et al., 2021). The potential for ethical issues such as data privacy and confidentiality increase with the possible access of digitized patient data for research use (Pillai et al., 2021). The potential to improve clinical practices to aid in treatment planning, reduced patient chair time, improve patient comfort, and reduce the number of visits will continue to fuel the adoption of digital dentistry (Cunha et al., 2021).

Dental 3D Printing

Dental 3D printing has evolved with 3D printing technology. Even though 3D printing has been applied to dentistry with high expectations since the late 1990s for mainstream usage, the development and implementation of applications have been slow (Chiu & Chen, 2022). The technology was limited to dental laboratories, but clinicians have found 3D printing more attainable in their practices since 2011 with the drop in 3D printer prices due to 3D printing patent expirations and specific dental applications developed (Fan et al., 2020; Turkyilmaz & Wilkins, 2021). Clinicians using 3D printing can fabricate parts based on a patient's unique physiology, providing a competitive advantage in individual medical and dental treatments (Dennies, 2021). Digital dentistry using 3D printing allows practitioners to create complex geometric forms using ceramic, plastics, and other materials from digital data and may revolutionize dentistry by making procedures less time-consuming and providing better quality care to patients (Chakraborty et al., 2021; Galante et al., 2019).

The impact of 3D printing has expanded the implementation and applications in different branches of dentistry. Clinicians in different branches of dentistry including oral surgery, prosthodontics, and orthodontics, have implemented 3D printing in their practices to various degrees (Huang et al., 2022). The current highest use of dental 3D printing occurs in oral surgery, prosthodontics, and orthodontics (Huang et al., 2022; Singh et al., 2022).

There are several applications of dental 3D printing. One application involves producing patient anatomical models for planning used in oral surgery (Jawahar &

Maragathavalli, 2019; Pillai et al., 2021). The patient specific models allow oral surgeons the ability to plan and practice a procedure before operating (Jawahar & Maragathavalli, 2019). Oral surgeons used 3D printing to produce surgical guides and templates for procedures such as implant placement (da Costa et al., 2021; Jawahar & Maragathavalli, 2019). The clinicians' use of guides and templates resulted in less invasive procedures that were more predictable and produced more accurate results (Pillai et al., 2021). However, some of the materials used to make templates or guides cannot be sterilized, limiting their application in procedures (Pillai et al., 2021).

Prosthodontics is another example of dental 3D printing application. The clinicians' process of replacing missing teeth is categorized as prosthodontics which provided more examples of dental 3D printing use (Singh et al., 2022). Clinicians have successfully used 3D printing to make dentures, implants, and crowns (Oberoi et al., 2018). Compared to conventional processes, the clinicians' use of 3D printing resulted in more accurate prostheses without requiring specific tooling while eliminating manual mistakes made by technicians (Singh et al., 2022). Clinicians have successfully incorporated 3D-printed metallic and polymer prostheses in their practices (Oberoi et al., 2018). However, one of the most popular materials used in prosthetics is ceramics which requires more research and development before successful 3D printing can be achieved (Prasad et al., 2018).

Orthodontics is another branch of dentistry using 3D printing. Orthodontists prevent, manage, and correct misaligned teeth (Francisco et al., 2022). Orthodontists use 3D printing to make clear removable aligners for milder cases of teeth misalignment

(Francisco et al., 2022). Clinicians printed molds from the patients' scan data and then vacuum thermoform the clear aligners out of silicone (Oberoi et al., 2018). Patients received new clear aligners every 2 weeks which are adjusted to gradually align teeth to the correct positions (Jawahar & Maragathavalli, 2019). Clinicians can change the 3D data to print new molds as required in the office resulting in decreased logistics and better patient outcomes (Shannon & Groth, 2021). However, clinicians cannot directly print aligners because of strict U.S. Food and Drug Administration material requirements for intraoral use (Shannon & Groth, 2021).

There are still hurdles to overcome for widespread dental 3D printing implementation. There are concerns regarding 3D printed objects exposed for long durations in an oral environment (Shannon & Groth, 2021). There are unknowns regarding the long-term dimensional accuracy of 3D printed dental objects (Kim et al., 2021). There are unknowns regarding the physical and mechanical properties of 3D printed objects when exposed to saliva, temperature changes, and the different chemicals individuals produce in the oral environment (Kim et al., 2021).

Dental 3D Printing Business Impacts

The 3D dental printing market continues to expand. The development of 3D printing technology since 2011 in dentistry has provided practitioners with in-house capabilities that were previously restricted to laboratories (Turkyilmaz & Wilkins, 2021). The current 3D printed dental market is valued at $3.2 billion with projections reaching $7.9 billion by 2027 with a compound annual growth rate of 20.2% indicating an upward trend in use in dentistry (Chiu & Chen, 2022). Nicali et al. (2022) forecasted that dental

3D printing will become the leading source for producing dental restorations worldwide by 2027 surpassing all current production processes. Berman (2020) reported the dental 3D manufacturing market grew from $780 million per year to over $3.1 billion in 2020.

The advantages of chairside or in-house 3D printing is fueling dental 3D applications. In-house 3D printing capabilities allow clinicians to deliver more accurate, cost-effective solutions while reducing treatment times (Turkyilmaz & Wilkins, 2021). Clinicians produce dental work onsite with increased complexity and greater economies of scale due to eliminating production restrictions such as tooling and fixturing (Kessler et al., 2020). Clinicians make personalized and customized patient-specific solutions due to the savings incurred on small-scale production using 3D printing (Oberoi et al., 2018). Practitioners using computer models and 3D printing fabricate new dental prostheses with minimal human labor allowing more restorations to be accomplished faster (Singh et al., 2022). Clinicians using 3D dental printing eliminate manual mistakes, reduce laboratory steps, and provide accurate prostheses to the patient resulting in higher patient satisfaction (Huang et al., 2022; Singh et al., 2022).

Dental 3D printing could have a positive impact on dental center profitability. Profitable dental clinics consider reduced patient chair time to decrease operational costs (Villias et al., 2022). Villias et al. (2022) found that complete dentures fabricated with a digital workflow reduced the standard five-visit workflow taught in dental school. However, this reduction was not apparent in practice because of legacy processes in use including an extra denture try-in appointment (Huang et al., 2022; Villias et al., 2022).

Another example of reduced chair time involves dental crowns. The current method for patients to receive dental crowns requires at least two visits over several weeks (Ishida et al., 2020; Kamali et al., 2022). Clinicians can reduce the wait time for patients to receive dental crowns by 1 to 2 days using crowns made with a 3D printer (Kamali et al., 2022).

Producing implant guides onsite provided another opportunity for dental 3D printing advantages. Yuan et al. (2019) studied making implant guides using a material extrusion 3D printer. The authors found that the chair-side production of the implant guides saved time, reduced costs, were highly accurate, and satisfied the clinical requirements (Yuan et al., 2019). Ahmad et al. (2022) documented similar results using implant guides for surgery.

There was a mixed impact for producing 3D printed metal appliances that would require further investigation. Shannon and Groth (2021) found that 3D printed metal appliances used by orthodontists cost more than conventional braces. However, the savings from the decreased number of visits, reduced chair time, and increased patient comfort required consideration when making decisions (Bentson & Copple, 2022; Shannon & Groth, 2021).

3D Dental Printing Challenges

Even with all the advantages dental 3D printing affords, there are still challenges for implementation. In addition to purchasing 3D printers, clinicians need supporting peripheral equipment such as intraoral scanners, CAD software, computer hardware, and internal office networks (Tian et al., 2021). Tian et al. (2021) also highlighted the high cost of equipment, material costs, and time-consuming post-processing as other barriers to implementation. Another concern for dental 3D printing relates to the availability of trained personnel to operate and maintain the equipment (Jawahar & Maragathavalli, 2019). Loges and Tiberius (2022) studied dental 3D printing implementation challenges by surveying 22 dental experts. Loges and Tiberius found that the greatest obstacle to dental 3D printing implementation was the lack of knowledge among the experts, followed by the high training effort of the staff and the experts' preference for conventional methods. The 3D printing aspect of digital dentistry requires additional research, education, a better return on investment, and improved productivity over conventional processes for fabricating dentures, aligners, implants, prosthetics, and guides before widespread implementation is achieved (Akyalcin et al., 2021).

With all these challenges, the future of dental 3D printing is unlimited (Schweiger et al., 2021). The equipment price will continue to drop, material availability will expand, and user-friendly processes will continue being developed, with chair-side functionality becoming more mainstream (Shaikh et al., 2021). Clinicians should prepare for the future by familiarizing themselves with the technology and keeping abreast of developments while assessing possible application areas (Schweiger et al., 2021).

Transition

In Section 1, I provided the problem for this study and the chosen research method and design. Section 1 included the research question, interview questions, and conceptual framework. Section 1 contained the operational definitions, assumptions, limitations, delimitations, and how the study might contribute to business practices and social change implications. Also, Section 1 provided an exhaustive literature review on DIT, previous studies that incorporated DIT, DIT tenets, and how DIT relates to 3D printing, specifically dental 3D printing.

Section 2 includes the role of the researcher, participants, research method and research design, population and sampling, ethical research, data collection instruments, data collection technique, data organization techniques, data analysis, and reliability and validity. Section 3 contains the findings, the study's application to professional practice, implications for social change, recommendations for action, suggestions for further research, reflections, and conclusions.

Section 2: The Project

Purpose Statement

The specific business problem is that some dental center leaders lack strategies to improve productivity using onsite 3D printing. The purpose of this qualitative multiple case study was to explore strategies that dental center leaders use to improve productivity using onsite 3D printing. The targeted population consisted of five different dental center leaders located in the United States who have successfully implemented strategies to improve productivity using onsite 3D printing.

Role of the Researcher

My role as a researcher was to serve as the primary instrument for data collection. The researcher selects participants; develops interview questions; determines the data that support answering the research question; collects the data through semistructured interviews, company websites, and publicly available information; interprets the data; and analyzes the data (Clark & Vealé, 2018). As the instrument for data collection, I used semistructured interviews in addition to information from company websites and publicly available information on dental 3D printing to collect data for this study, interpret the data, and analyze the data relative to answering the research question.

My interest in conducting this research came from a personal curiosity about the future implications of 3D printing on businesses. During my career as an automotive manufacturing engineering manager, I was exposed to technologies that were considered disruptive, such as the use of robotics. Although these technologies significantly impacted manufacturing strategies, they never achieved the expected disruption level.

The challenge for me was studying a topic where I had no background or affiliations with potential participants, which made it difficult to access my population to collect data and answer my research question.

To uphold ethical research standards, I followed the protocol outlined in the *Belmont Report* (U.S. Department of Health and Human Services, 1979). The guidelines in the *Belmont Report* ensure the protection of participants' human rights involved in the research process through a moral framework by emphasizing respect for persons, beneficence, and justice (Redman & Caplan, 2021). The two ethical convictions the researcher should address to support respect for persons are to treat individuals as autonomous agents and to protect those persons with diminished autonomy (U.S. Department of Health and Human Services, 1979). Researchers strive to achieve beneficence by providing forethought to maximize the benefits while reducing the risks that might occur from the research with the goal to do no harm (U.S. Department of Health and Human Services, 1979). I informed the participants through the informed consent process of the benefits and risks involved with their participation to safeguard beneficence. Justice requires fairness when selecting participants related to who receives the benefits or bears the burden of the research and is achieved by choosing subjects directly related to the problem being researched (U.S. Department of Health and Human Services, 1979). I treated all participants equally and protected their privacy by informing participants of the criteria for their selection and keeping all records private regarding each individual to achieve justice. Upon approval from The Walden University

Institutional Review Board (IRB) and informed consent obtained from all potential participants, I proceeded with the data collection process.

As a qualitative researcher, I needed to be conscious of personal biases and strived to minimize those biases from influencing the results of the study. An advantage of not having a background or contacts in the population is that any personal bias was likely mitigated by allowing participants to express their personal views while avoiding viewing the data through a personal lens. As a researcher, the challenge to accurately capture interview responses can be minimized through member checking. Member checking is the iterative process where the researcher shares interpreted responses with the participant for validation purposes to ensure data accuracy (Naidu & Prose, 2018). A reflective journal allows the researcher to capture their thoughts and ideas during data collection (Houghton et al., 2013). I logged my evolving perceptions during the data collection process, recorded the day-to-day procedures, captured personal introspections, and comprehended methodological decision points in a reflective journal. I documented my thoughts and ideas in a reflective journal during the interviews to aid in the development of themes, followed the interview protocol (See Appendix C), and performed member checking to mitigate bias in my research.

I used an interview protocol to help guide me through the semistructured interviews. Developing an interview protocol aids the interviewer in creating the interview process by developing a roadmap the interviewer follows with cues of what to say and do during the interview (Yeong et al., 2018). The researcher develops a set of consistent interview questions that do not vary between participants as part of the interview protocol, ensuring rich data collection from the interviews (Weller et al., 2018; Yeong et al., 2018).

Participants

The eligibility of participant selection for this study ensured that each participant's characteristics aligned with the research question (see DeJonckheere & Vaughn, 2019). Participant selection in a qualitative study aims to increase the depth of participants' experience to support a relatively small sample size (Campbell et al., 2020). The research question for this study was as follows: What strategies do dental center leaders use to improve productivity using onsite 3D printing? The eligibility criteria for this study were as follows: (a) Dental center leaders who have successfully implemented strategies to improve productivity using onsite 3D printing, (b) dental center leaders with a minimum of 5 years in a leadership position, and (c) dental center leaders with a minimum of 2 years clinical experience using 3D printing.

The first step was to identify potential participants from the population of United States dentists who met the participant eligibility criteria. I joined the LinkedIn group Dental 3D Printing Scanning Design & CAD CAM Milling in Dentistry at www.d3d.us and the 3D printing – dentistry group at https://www.linkedin.com/groups/13796103/. I identified the U.S. dentists participating in the groups and searched for them online using Google. I contacted dental 3D printing equipment suppliers including Sprint Ray at 1-800-914-8004 and Nexdent at 1-888-598-1438 to provide a list of dentists who have purchased 3D printing equipment for their clinics.

Liu (2018) stated that conducting successful interviews requires gaining access and establishing trust with participants. Once I identified a population of potential participants, I emailed a letter of invitation (see Appendix B), including research objectives, participant selection criteria, my commitment to confidentiality, and how their participation was voluntary to help build trust. I followed up the email via a phone call with those who responded to my letter of invitation. During the conversation, I explained the time commitment for their participation, informed the potential participants of what I would do with the information collected, reaffirmed my commitment to confidentiality, and explained how their responses would contribute to the research. I explained how I will share the research results that may help them learn how competitors are approaching the study phenomenon. During the second follow-up call, I explained the informed consent process, addressed any questions or concerns, and explained the procedure to withdraw at any point during the process. I also addressed concerns about their personal and organizational confidentiality by clarifying the use of a coding system such as P1 for participant one and C1 for company one as a way to build trust with the potential participants. I requested that the potential participants respond to my Walden.edu email agreeing to the consent form terms with the statement “I consent” if they were interested in being interviewed.

I selected the first five participants who agreed to participate in the study. I set up a communication plan that included specific dates, times, and preferred interaction medium using only the audio capabilities by Zoom or Skype with the participants for the interview and follow-up member checking process that best supported their availability and communication preference. According to Boland et al. (2021), Zoom and Skype are audio/video conferencing platforms commonly used for interpersonal communication. I notified the participants that I would be recording the audio depending on the preferred communication medium of Skype or Zoom of the interviews while following an interview protocol to ensure consistency between the interviews. Member checking is the iterative process where the researcher shares interpreted responses with the participant for validation purposes to ensure data accuracy (Naidu & Prose, 2018). I communicated the member checking process to the participants, so they understood the additional interaction required to confirm their responses. I shared my flexibility to accommodate their schedules by providing my availability schedule and my Walden.edu email address if they needed to make any changes.

Research Method and Design

Research Method

The research methods available for researchers are qualitative, quantitative, and mixed (Paoletti et al., 2021). Researchers using the qualitative method ask open-ended questions about human experiences through participant interviews in the participants' natural environments (Renjith et al., 2021). The researcher's goal of the interviews is to understand the interviewee's realities by gathering descriptive data that comprehends their experiences (Renjith et al., 2021). Qualitative research involves understanding an individual's insight and perceptions of a phenomenon (Yin, 2018). Qualitative researchers generally perform semistructured interviews that use open-ended questions focusing on the *how*, *what*, or *why* of a phenomenon and are suitable for comprehending underexplored phenomena where researchers make assertions based on their findings, compare findings to existing literature, and suggest future research topics (Peterson, 2019; Yin, 2018). The researcher attempts to answer the research question using the qualitative method by generating and analyzing the rich narrative from the results of semistructured interviews (Rutberg & Bouikidis, 2018). Researchers often use the qualitative method when there is a desire to study a little known, unexplored, underexplored, or a poorly understood phenomenon (Rutberg & Bouikidis, 2018). I selected the qualitative method because I asked participants *how* and *what* questions to address the research question of the underexplored phenomenon of how onsite dental 3D printing improves productivity.

Quantitative researchers collect numeric data by standardized questionnaires, surveys, secondary data sets, causal relationship questions, or laboratory experimental methods in a structured environment allowing the researcher to have control over study variables (Rutberg & Bouikidis, 2018). Quantitative researchers measure and determine relationships between variables and outcomes (Ahmad et al., 2019). Quantitative researchers then draw conclusions that address the research question by developing and testing hypotheses for examining variables' characteristics, relationships, or group differences (Ahmad et al., 2019). Researchers use mixed method to combine characteristics of quantitative and qualitative methods in the same study (Paoletti et al., 2021). Quantitative and mixed method research were not appropriate for this study because measuring and determining relationships between variables and outcomes through developing and testing hypotheses for examining variables' characteristics, relationships, or group differences would not have addressed my research question.

Research Design

I considered three research designs for the study: case study, phenomenological, and ethnographic. Using a case study design, the researcher explores a contemporary phenomenon in a real-life setting, where the researcher has little or no control over behavioral events (Yin, 2018). Case study is the preferred research design to explore participant responses on a particular subject regarding a single person, team, or organization (Alam, 2020). The case study researcher explores a program, event, activity, or process through in-depth data collection from multiple sources within a defined time frame and bounded by place (Alpi & Evans, 2019).

Researchers using a phenomenological design seek to explore a phenomenon through individuals' personal meanings and lived experiences (Neubauer et al., 2019). Researchers using a phenomenological design attempt to capture the way a phenomenon was lived by people who participated in the phenomenon (Tomaszewski et al., 2020). Tomaszewski et al. (2020) stated that phenomenological research is often used in studies focusing on the essence of people's lived experiences.

Researchers use ethnographic design to explore complex cultural settings, norms, trends, and social systems through long-term engagement by acquiring observational and interview evidence (Andreassen et al., 2020). Researchers using ethnographic design may require extensive fieldwork relying heavily on observational skills for extended periods of time (Tomaszewski et al., 2020). I did not choose phenomenological design for my study because I did explore individual lives or shared life experiences. I also deemed ethnographic design inappropriate for my study because I did not seek to explore cultural norms through extensive fieldwork. Instead, I selected case study design to explore a real-world phenomenon bounded by time and place to understand the context of the phenomenon to answer the research question.

Data saturation is achieved when no new information, codes, or themes are generated from data sources (Alam, 2020). Researchers using multiple data sources can develop convergent evidence to achieve data saturation through the process known as triangulation (Yin, 2018). I used multiple data collection techniques including interviews, company websites, and publicly available information on dental 3D printing to achieve data saturation.

Population and Sampling

The targeted population for this qualitative multiple case study was five dental center leaders in the United States who have successfully implemented strategies to increase productivity using onsite 3D printing. To be eligible to take part in the study, participants were required to have had at least 5 years in a dental center leadership position, a minimum of 2 years of clinical experience in increasing productivity using onsite dental 3D printing, and had successfully implanted strategies to improve productivity using onsite dental 3D printing. Choosing a sample size is key to achieving data saturation, and there are a multitude of recommendations on the optimum number for a case study. Sim et al. (2018) suggested case study sample sizes between four and 30. Roy et al. (2015) surmised that a researcher could achieve data saturation in a qualitative case study with three to five participants. Contrarily, Onwuegbuzie and Leech (2007) suggested there is not a standard number of interviews and reviewing previous studies using the same research design that achieved data saturation when determining sample size. Thus, I chose a minimum sample size of five participants from the population who met my eligibility criteria.

I used purposeful sampling to select dental center leaders who met the eligibility criteria. Researchers use purposeful sampling to conduct an in-depth exploration of information-rich sources to gain insight into a phenomenon (Bush & Amechi, 2019). Researchers use purposeful sampling to select participants with in-depth knowledge and experience of the study phenomenon (Doyle et al., 2020). Researchers using purposeful sampling identify participants through specific criteria related to the study phenomenon (Bush & Amechi, 2019). I chose purposeful sampling for this study based on study criteria and the relevance and richness of information needed to understand the specific nature of onsite dental 3D printing productivity improvements with the participants' in-depth knowledge and the limited amount of data available on the subject.

The data saturation process involves the identification of (a) themes, (b) thematic definitions, (c) categories, and (d) coding based on the participants with the researcher achieving data saturation after they confirm that no new themes, thematic definitions, categories, or coding are apparent. I verified data saturation after the collected data was analyzed and determined no new themes, categories, insights, or perspectives for coding were apparent.

I conducted 30 to 45-minute semistructured interviews using only the audio capabilities by Zoom or Skype that best supported the participants' and my availability and communication preference. According to Boland et al. (2021), Zoom and Skype are audio/video conferencing platforms commonly used for interpersonal communication. I confirmed the participants' preferred communication method and emailed them an invitation with instructions on how to access Zoom or Skype. I informed the participants to disable the camera feature on Zoom or Skype and to use a headset to protect confidentiality. I notified the participants that I would be recording the audio depending on the preferred communication medium of Skype or Zoom using the audio recording features on Zoom or Skype. To minimize distractions, I requested that the participants were in a private setting and turn off phone notifications and I did the same.

Ethical Research

Adherence to ethical standards is required by researchers during the research process to ensure the protection of human subjects (Yin, 2018). I obtained permission from Walden University's Institutional Review Board (IRB) which ensures ethical standard adherence prior to proceeding with data collection.

The National Research Council (2003) stated one of the requirements for adhering to ethical standards during the research process is acquiring informed consent with a formal solicitation alerting the participants to the nature of the study and receiving a formal response prior to being interviewed. After participants responded to the invitation letter willing to participate in the study, I emailed information that included (a) interview procedures, (b) the voluntary nature of the study, (c) the risks and benefits of being in the study, (d) participant privacy measures, and (e) IRB contact information for participant questions. I contacted potential participants via email or telephone to address any issues or concerns they had regarding participating in the research study, explained the expected time commitment for their participation, informed the potential participants of what I will do with the information collected, affirmed my commitment to confidentiality, and explained how their responses will contribute to the research. I requested that the potential participants respond to my Walden.edu email agreeing to the interview terms with the statement “I consent” if they were interested in being interviewed.

At the initial meeting, I mentioned that participation in the research study was voluntary with the ability to withdraw from the study at any time without consequence by notification via my Walden.edu email. Any information collected from a withdrawn participant would be destroyed by shredding written documentation or deleting electronic information and would not be used in the study.

To ensure the ethical protection of participants was adequate I followed the protocol outlined in the *Belmont Report* (U.S. Department of Health and Human Services, 1979). The guidelines in the *Belmont Report* ensure the protection of participants’ human rights involved in the research process through an ethical framework by emphasizing respect for persons, beneficence, and justice (Redman & Caplan, 2021). I ensured the ethical protection of the participants by communicating via email the intent of the study, the voluntary nature of the study, the risks, and benefits of participating in the study, the privacy measures incorporated to protect participants, and the ability for participants to withdraw from the study at any time.

A vital aspect of ethical research requires maintaining participant and participant organization confidentiality (Noble & Smith, 2015). The National Research Council (2003) stated the importance of protecting participant privacy and confidentiality. I used codes to address concerns about participants' personal and organizational confidentiality by clarifying the use of a coding system such as P1 for participant one and C1 for company one. The researcher is responsible for maintaining participant and participant organization confidentiality (Ngozwana, 2018).

All study documentation including interview transcripts, and interview recordings will be securely stored for 5 years from Chief Academic Officer (CAO) designee approval. Paper documents were stored in a fireproof safe located in my home office which I have the only key and all electronic documentation was stored on a password-protected universal serial bus (USB) flash drive and also kept in my personal fireproof safe. After 5 years, the paper documents will be shredded in my cross-cut shredder and the USB flash drive will be reformatted to erase all data. The IRB approval number for this study was 03-14-23-1037990.

Data Collection Instruments

I functioned as the primary data collection instrument to explore strategies dental center leaders use to improve productivity using onsite 3D printing. The researcher serves as the primary instrument for data collection and analysis in qualitative research (Clark & Vealé, 2018). Yin (2018) stated a minimum of two data collection methods is required to achieve triangulation in case study research. I used semistructured interviews as the primary data collection method for this study. In addition to conducting semistructured interviews, I reviewed company websites and publicly available information on dental 3D printing for my secondary data collection method.

Open-ended questions and the use of an interview protocol characterize semistructured interviews (Busetto et al., 2020). The interactive nature of semistructured interviews allows unexpected concepts and ideas to emerge during the exchange between the interviewer and interviewee which can enhance the data richness (Busetto et al., 2020). Using an interview protocol provides a roadmap the interviewer follows with cues of what to say and do during the interview (Yeong et al., 2018). The researcher develops a set of consistent interview questions that do not vary between participants as part of the interview protocol ensuring rich data collection from the interviews (Weller et al., 2018; Yeong et al., 2018).

I used semistructured interviews to collect data from five dental center leaders who had successfully implemented strategies to increase productivity using onsite 3D printing. I kept questions consistent between interviewees by following an interview protocol and documenting notes in a reflective journal during the interviews. A reflective journal allows the researcher to capture their thoughts and ideas during data collection (Houghton et al., 2013). In addition to the reflective journal, I recorded the audio for each interview on the Zoom or Skype application.

I used member checking to enhance the reliability and validity of the data collection process. Member checking is the iterative process where the researcher shares interpreted responses with the participant for validation purposes to ensure data accuracy (Naidu & Prose, 2018). I shared my documentation of the interviews with each participant and followed up with a phone call or email within one week of the initial interview to confirm I had captured the interviewees' responses accurately.

Data Collection Technique

I used semistructured interviews as my primary data collection technique. Researchers choose a specific data collection technique such as document study, focus groups, semistructured interviews, or observations that best enables answering the research question (Busetto et al., 2020). I contacted potential participants who met the eligibility criteria for interviews after receiving IRB approval.

The first contact with potential participants by email contained a letter of invitation (see Appendix B) including research objectives, participant selection criteria, my commitment to confidentiality, and how their participation was voluntary. I followed up on the email via a phone call with those who responded to my letter of invitation. During the conversation, I explained the time commitment for their participation, informed the potential participants of what I will do with the information collected, reaffirmed my commitment to confidentiality, and explained how their responses would contribute to the research. I also explained the informed consent process, addressed any questions or concerns, and explained the procedure to withdraw at any point during the process. I agreed on an interview date and time and preferred method, Zoom or Skype with each participant and followed up with an email confirmation from my Walden.edu email. Zoom and Skype are audio/video conferencing platforms commonly used for interpersonal communication (Boland et al., 2021).

Researchers using open-ended questions and following an interview protocol characterize semistructured interviews (Busetto et al., 2020). I followed an interview protocol to ensure consistency between all interviews. Using an interview protocol provides a roadmap the interviewer follows with cues of what to say and do during the interview (Yeong et al., 2018). I started the interview with an introduction and thanked the participants for their participation. I followed the introduction by asking the seven interview questions, continued with follow-up questions that emerged during the conversation, and concluded by thanking the participant and scheduling the follow-up member checking interview. I asked for the participant's approval to audio record the interview and confirmed the video camera was disabled for the interview. I also took notes during the interview to supplement the audio recordings with my observations.

I transcribed the audio recordings and summarized each interview before the member checking interview. I emailed a summary of my interpretations from the initial interview within one week to each participant for their review prior to the member checking interview. During the member checking interview, I confirmed that I had accurately captured the participants' responses and made corrections to reflect the interviewees' replies. Member checking is the iterative process where the researcher shares interpreted responses with the participant for validation purposes to ensure data accuracy (Naidu & Prose, 2018).

There are advantages and disadvantages to using semistructured interviews as a data collection technique. Advantages of using semistructured interviews include: (a) capturing unexpected concepts and ideas that can emerge during the exchange between the interviewer and interviewee which can lead to data richness (Busetto et al., 2020), (b) interviewees can relate their experiences by speaking freely and in their own words (Ergul Sonmez & Koc, 2018), and (c) semistructured interviews allow the freedom for the interviewer to ask additional probing questions that may arise while following the prepared interview protocol (Barrett & Twycross, 2018). Disadvantages of using semistructured interviews include: (a) the open exchange may derail the interview by allowing the interviewee the opportunity to go off on a tangent (Yeong et al., 2018), (b) the potential for the interviewees to have poor recall or the inability to verbally communicate their thoughts (Yin, 2018), and (c) researcher bias may influence participant responses through opinionated interview questions (Barrett & Twycross, 2018).

Data Organization Technique

Williams and Moser (2019) emphasized that data organization should be clear and repeatable to enable data analysis. All electronic data I gathered including interview transcripts, member checking interpretations, member checking responses, electronically recorded interviews, and the data coding analysis is stored on my password-protected Dell Inspiron laptop computer. The primary folder is named Zamaniancapstone and contains overall study information with subfolders named by company designation such as C1 for company one. The company folders contain all electronic information relative to that company with subfolders such as P1C1 containing all information relative to each participant from that company. All the paper documentation including my reflective journal, handwritten interview notes, and company information are stored in manilla folders and labeled similarly to the computer folder system. The electronic folders are backed up on a password-protected USB flash drive. Noble and Smith (2015) stressed the importance of storing raw data in a central location with a predetermined file naming convention.

After CAO designee approval, the electronic data will be deleted from my laptop and stored on my password-protected USB flash drive. All study documentation will be securely stored for 5 years from CAO designee approval. Paper documents will be stored in a fireproof safe located in my home office which I have the only key and all electronic documentation will be stored on a password-protected USB flash drive kept in my fireproof safe. After 5 years, the paper documents will be shredded in my cross-cut shredder and the USB flash drive will be reformatted to erase all data.

Data Analysis

Researchers who follow detailed steps for qualitative data analysis can present the results in a logical manner allowing for better data interpretation and leading to potentially significant research conclusions (Akinyode & Khan, 2018). The researcher organizes the data, codes the data, develops themes from the codes, and interprets results to answer the research question through data analysis (Roller & Lavrakas, 2018).

The major strength of qualitative research allows the researcher to use multiple sources of data to confirm the consistency of a researcher’s findings (Yin, 2018). Methodological triangulation is a method researchers use to enhance the reliability and validity of research findings through the evaluation of multiple data sources (Noble & Heale, 2019). Different data sources for a study that lead to the same results give the researcher and readers greater confidence in the research findings (Yin, 2018). I achieved methodological triangulation by collecting data with semistructured interviews, company websites and publicly available information on dental 3D printing.

Yin's 5 Step Data Analysis Process

Yin (2009) recommended that researchers build a data analysis strategy during the development of a case study research project. Yin noted that the researcher should rely on their own style of rigorous thinking when analyzing data and interpreting alternatives due to the lack of structured analysis tools for case study research. Yin outlined a 5-step process as compiling, disassembling, reassembling, interpreting, and concluding for qualitative data analysis. I followed Yin's 5-step data analysis process in my study.

Compiling

Compiling is the first step in data analysis (Castleberry & Nolen, 2018). Castleberry and Nolen (2018) indicated compiling is the process where the researcher gathers all the research data, familiarizes themselves with the data, and organizes the data into a usable format for analysis. Microsoft Word is a standard word processing software that researchers can use to organize and code data including participant interviews and company documents (Watkins, 2017). After I completed the semstructured interviews, I compiled and transcribed the interviews into Microsoft Word documents. After I completed the Word transcription process, I reviewed the documents and color-coded themes that emerged during the data analysis process. For better data sorting and analysis, I transferred the color-coded themes from Microsoft Word to a Microsoft Excel spreadsheet. Nowell et al. (2017) specified that a Microsoft Excel spreadsheet provides advantages for sorting data and data analysis. Researchers can sort data by color codes using tools available in Excel software (Williams & Moser, 2019).

During the process of reading and reviewing the semistructured interview transcripts and company documents, I documented my thoughts, experiences, and actions in a reflective journal. A reflective journal allows the researcher to capture their thoughts and ideas during data collection to aid in identifying emerging themes and patterns (Houghton et al., 2013). I reviewed the data to code and analyze it after I read the transcripts from the semistructured interviews, company websites and publicly available information on dental 3D printing. After data compilation was complete, I disassembled the data.

Disassembling

Doyle et al. (2020) specified that disassembling data to focus on individual categories is the second step of data analysis. The process researchers use to establish meaning by labeling and organizing data is called coding (Doyle et al., 2020). Coding is a systematic process qualitative researchers use to identify repeated content in data that helps researchers identify interrelated parts of different data sources (Clark & Vealé, 2018). Doyle et al. indicated qualitative researchers identify concepts and themes through the process of coding. Williams and Moser (2019) stated the importance of taking notes during the coding process to explain code content and aid the researcher when recalling pertinent facts to support the research question. I read the transcripts, captured additional notes as I read the transcripts, and reviewed my journal notes to start the coding process. During this review, I identified relevant words and phrases that could answer the research question and highlighted them with color codes. I iterated the coding process until data saturation was achieved. Data saturation is achieved when iterations yield repeated information and no new codes or themes are generated from multiple data sources including interviews, company websites and publicly available information on dental 3D printing (Alam, 2020). I repeated the coding process to seek additional codes until no more were discovered. A repetitive review process allows the researcher to familiarize themselves with the data and gain a deeper understanding of the data to aid in achieving data saturation (Castleberry & Nolen, 2018).

Reassembling

Reassembling is the third step in data analysis where the qualitative researcher identifies patterns and themes (Castleberry & Nolen, 2018). Qualitative researchers can use coding techniques to translate data into usable information during the analysis process (Williams & Moser, 2019). Qualitative researchers can identify repeated themes from the coded data after transcribed semistructured interviews have been organized and sorted by keywords and concepts (Bush & Amechi, 2019). Williams and Moser (2019) stated that the repetition of words and phrases within the data could aid the qualitative researcher in identifying themes. I highlighted keywords and phrases during several iterations of coding and then transferred the emergent themes into a Microsoft Excel spreadsheet. I compiled, organized, and summarized the main concepts in a master list. I compared the main concepts and participant responses to identify common themes and relationships that answered the research question. Williams and Moser suggested when dealing with multiple sources of data the qualitative researcher can break down the data into smaller categories and focus on each category. I assigned names and grouped common themes that related to the phenomenon and supported answering the research question. At the conclusion of coding and synthesizing, I compared the data to the literature and conceptual framework to ensure alignment.

Interpreting

Interpreting data is the fourth step in data analysis where the qualitative researcher becomes familiar with the meaning of the data and makes analytical conclusions from the findings **(**Castleberry & Nolen, 2018). I continued to interpret the data after reassembling the data into patterns and themes. The qualitative researcher focuses on answering the research question when determining the significance of the findings postulated from code interpretation and theme development (Bush & Amechi, 2019). Castleberry and-Nolen (2018) noted that qualitative researchers aligning the interpretations with the research question is critical to capturing concepts of importance to the overall research question rather than simply restating codes and themes. I interpreted the data to confirm the relationship between codes and emerging themes to support answering the research question. Qualitative researchers ensure alignment between data interpretation and the conceptual framework by correlating the evidence to the conceptual framework principles (Renjith et al., 2021). I reviewed and compared evidence from the data, literature, and conceptual framework to confirm the alignment of the research.

Concluding

Concluding is the final step in qualitative data analysis where the researcher presents their findings and conclusions derived from the previous data analysis steps

(Castleberry & Nolen, 2018). Busetto et al. (2020) emphasized that the researchers' conclusions provide a summary of how their findings provide a response to the research question. I supported my findings and conclusions with my interpretations and examples from the data in the form of text for readers. I provided a summary of my findings via email to each participant after the study publication by Proquest. I pursued alignment between my findings and the conceptual framework in this qualitative study. I reviewed the current literature related to my findings and the conceptual framework after I developed my conclusions. I incorporated any significant new evidence found in the current literature to support my study as it correlated with the conceptual framework.

Conceptual Software Application Plan

I used Microsoft Word to organize and code the transcribed data. To facilitate creating a coded text table from the transcribed data, I used Microsoft Word functionality for comments, tracking features, and macros. I exported the Microsoft Word text table to Microsoft Excel and pasted the coded text tables into the spreadsheet to classify, sort, and analyze the data. I identified themes from the semistructured interviews that aligned with DIT. I grouped, reviewed, and compared similar codes using Microsoft Excel and color functions to correlate the themes to DIT and existing literature findings for the purpose of analyzing and interpreting the data. The knowledge gap between theory and practice may be closed when research findings correlate with existing literature and the conceptual framework referenced by the researcher (Nowell et al., 2017).

Reliability and Validity

Reliability

Lincoln and Guba (1985) surmised that dependability for qualitative research is synonymous with reliability for quantitative research. Dependability relates to the degree research procedures are documented and the level of consistency and reliability of the research findings (Nowell et al., 2017). A researcher achieves dependability when the research process can be followed, audited, and critiqued by an outside party to validate research results (Nowell et al., 2017) Member checking is a method researchers can use to ensure reliability (Lincoln & Guba, 1985; Yin, 2018). Researchers can also enhance reliability through the code-recode process and by triangulating data from different sources (Anney, 2014; Yin, 2018). I member checked the interview results by confirming, clarifying, and correcting responses with each participant. I coded the data and then re-coded the data after two weeks to confirm if the results were similar or different and I triangulated the data from the interviews, company websites, publicly available information, and literature to further enhance dependability.

Validity

The three aspects of qualitative validity include credibility, confirmability, and transferability (Morse et al., 2002). Qualitative validity relates to the trustworthiness of the research with the data interpreted to provide an accurate representation of the participants' intent through the attainment of credibility, confirmability, and transferability (Lincoln & Guba, 1985).   Researchers can persuade themselves and readers that the research findings are worthy of attention by attaining trustworthiness (Nowell et al., 2017).

Credibility

Qualitative researchers achieve credibility when they are confident in the truth of the research study's findings (Anney, 2014). Criteria for attaining credibility involves the establishment that the research findings are believable or credible from the participants' perspective (Anney, 2014). Lincoln and Guba (1985) identified several techniques to achieve research credibility including prolonged engagement, triangulation, peer debriefing, negative case analysis, and member checking. Researchers should determine which techniques they will use during the research design phase because all techniques may not be suitable (Korstjens & Moser, 2018). I achieved research credibility through methodological triangulation and member checking.

Confirmability

Anney (2014) stated that when research results can be confirmed or validated based on participants' responses by others, the research exhibits confirmability while mitigating potential bias or a researcher's personal motivations. A researcher can use an audit trail to ensure confirmability by recording the research steps throughout the study (Anney, 2014; Korstjens & Moser, 2018). Anney surmised that an audit trail, reflective journal, and triangulation enable a researcher to achieve confirmability. I achieved confirmability through methodological triangulation and member checking to ensure I had captured the participants' views while mitigating my biases.

Transferability

Transferability is achieved when a qualitative researcher demonstrates that their study's findings are applicable to other contexts such as similar situations, populations, and phenomena (Anney, 2014). Anney concluded that researchers should document all the research processes from data collection through the final report providing a thick description to other researchers who may want to replicate the study under similar conditions. A researcher provides a thick description by detailing the methodology and context of the research with particulars on all the specifics of the research process (Anney, 2014). I obtained transferability by using purposive sampling and providing details of the research process including data collection, the context of the study, and final report generation.

Data Saturation

Data saturation is achieved when coded iterations yield repeated information and no new codes or themes are generated from multiple data sources including interviews, and publicly available information (Alam, 2020). A repetitive review process allows the researcher to familiarize themselves with the data and gain a deeper understanding of the data to aid in achieving data saturation (Castleberry & Nolen, 2018). The data saturation process involves the identification of: (a) themes, (b) thematic definitions, (c) categories, and (d) coding based on the participants with the researcher achieving data saturation after they confirm that no new themes, thematic definitions, categories, or coding are apparent. I verified data saturation after the collected data was analyzed and determined if no new themes, categories, insights, or perspectives for coding were apparent.

Transition and Summary

In Section 2, I provided the role of the researcher, participants, research method and research design, population and sampling, ethical research, data collection instruments, data collection technique, data organization techniques, data analysis, and reliability and validity.

Section 3 contains the findings, the study's application to professional practice, implications for social change, recommendations for action, suggestions for further research, reflections, and conclusions.

Section 3: Application to Professional Practice and Implications for Change

Introduction

The purpose of this qualitative multiple-case study was to explore strategies that dental center leaders use to improve productivity using onsite 3D printing. Using semistructured interviews, I acquired data from five dental center leaders who employed effective strategies to improve productivity using onsite 3D printing. As shown in Table 1, the dental center leaders represented various types of dental care providers. They served different roles with varying years of experience as dental practitioners. I collected data until I reached data saturation. After conducting three interviews, I conducted a preliminary data analysis. After each subsequent interview, I assessed if the interview yielded any additional themes or information relevant to the study. After five interviews, I concluded that I had reached the data saturation point because the additional interview did not yield any new themes or information.

I used thematic analysis in this study to identify patterns and themes from the data. Three themes emerged: enabling technology strategy, innovative business model strategy, and customer demand strategy. This section includes the presentation of the findings, the study's application to professional practice, implications for social change, recommendations for action, suggestions for further research, reflections, and conclusions. Table 1 summarizes participant demographics.

Table 1

Participant Demographic Summary

Participants	Years of experience	Organization	Role
P1	25	Private practice	Practitioner/ owner
P2	11	Corporate dental network	Executive
P3	20	Private practice/ hospital system	Practitioner/ leader
P4	20	Private practice	Practitioner/ owner
P5	27	Private practice/ hospital system/ university	Practitioner/ leader/ professor

P1 was a practicing dentist and owner of a dental center with five other practicing dentists. P1 held a Mastership Academy of General Dentistry designation, a top-level award of the Academy of General Dentistry given to only those dentists who have first achieved Fellowship, passed a rigorous written test, and completed over 500 hands-on credit hours in the subspecialties of dentistry. P1 also held a Fellow of the International Congress of Oral Implantologists and reflected his training and experience with dental implants.

P2 received a diploma as a denturist. P2 owned a chain of denture specialty centers. P2 sold the denture centers to become an executive at a large dental organization. P2’s role focused on the latest innovations brought to production for removable prosthetics in the organization’s dental centers.

P3 was a general dentist that specialized in prosthodontics. P3 practiced in a large hospital and in a private practice. P3 initiated the dental 3D printing process at both facilities.

P4 was the owner and only dentist in a private dental office. P4 served in the US Navy and used the GI bill to fund his dental education. P4 practiced almost all areas of dentistry but took a special interest in implant dentistry.

P5 practiced in a large hospital system, private practice, and was professor at a dental university. P5 was a member of the American College of Prosthodontists where he was also a member of the task force developing digital curriculum nationally. His areas of research included optical scanners, digital dentures, and reinforcement of dentures.

Presentation of the Findings

The research question of this study was as follows: What strategies do dental center leaders use to improve productivity using onsite 3D printing? In this study, I interviewed five dental center leaders who have successfully implemented strategies to improve productivity using onsite 3D printing. Each leader had a minimum of 2 years of experience with onsite 3D printing and at least 8 years of experience with digital dentistry. Productivity relates to providing more economic value through lower costs and higher quality. I reviewed the data and identified themes that matched the theoretical constructs of DIT. I coded the data to match patterns connected to DIT principles. Three themes emerged: enabling technology strategy, innovative business model strategy, and customer demand strategy. Table 2 shows the themes tied to the conceptual framework.

Table 2

Themes Tied to Conceptual Framework

Theme title	Corresponding DIT principle	Theme definition
Enabling technology strategy	An enabling technology	The participants used enabling technology strategies to incorporate onsite dental 3D printing into their operations.
Innovative business model strategy	An innovative business model	The participants used innovative business model strategies to maximize positive business impacts using onsite dental 3D printing.
Customer demand strategy	Consumer demand influence	The participants followed customer demand strategies to optimize positive consumer impacts using onsite dental 3D printing.

Theme 1: Enabling Technology Strategy

An enabling technology refers to an innovation, such as onsite 3D printing, that has the potential to cause market disruption by drastically improving the performance or capabilities of products and services. The enabling technology strategy theme comprises strategies and actions the participants adopted to incorporate onsite 3D printing into their operations. All the participants researched 3D printing applications for their practices. The participants worked with different vendors to determine which systems would best fit their practices before purchasing equipment. The participants determined the location for the equipment within their facilities, prepared the areas for the equipment, and set up a plan for using and maintaining the equipment. P2 explained the process their organization followed with one vendor:

> When you look at a company like Sprint Ray, and when you look at what they've done, they call themselves chemistry for dentistry and not just a materials company, but also really innovating hardware. They helped us get organized so that we could start 3D printing in office.

When implementing these enabling technology strategies, there were different approaches by the participants. P2, P3, and P5 had the backing of larger organizations and resources to facilitate their enabling technology strategy. P3 and P5 were part of a major hospital system that provided funding and resources to support their enabling technology strategy. P2 was part of a large independent corporation that also provided funding and resources to enable their technology strategy. P2 elaborated on the enabling technology strategy through a digital transformation:

> So fast forward to today, when you look at, okay, so you have over a thousand locations. How do you go through a digital transformation? Well, we've already been using intraoral scanning technology for the last eight years. So we had iTero scanners put into all of our offices eight years ago. Which kind of started that transformation. So digital technology is not something new to us, but how do we really look at digital transformation? And that's having an intraoral scanner on site and a 3D printer on site. So to date we have deployed 1300 new 3Shape TRIOS intraoral scanners to all locations and 220 3D printers out there in our locations.

On the other hand, the other participants did not have the backing of large organizations. P1 and P4 followed a different approach to their technology enabling strategy being smaller independent entities. P1 was able to bring a technically astute dentist into the practice to plan their enabling technology strategy. P4 was limited because he was the only person in the practice to determine an enabling technology strategy. P1 described how their practice was able to hire an expert to lead their enabling technology strategy:

> So for me, I, I'm fortunate in that I have a dentist that came in with me at the same time we started implementing this about, I think it was about five years ago. And he was a really a great resource because he was really technologically savvy, but he was reaching a point in his practice where he was contemplating retirement, and this offered him kind of like another career. So it extended his career. He's in my practice now and is really our go-to person in terms of digital design and implementation of a lot of the technologies. So he's someone that is, he is 69 years of age right now and still going strong and can run circles around. Other people wouldn't even have an idea of how to approach this stuff.

Another example of different approaches for implementing the enabling technology strategies centered on the timeline for onsite 3D printing adoption. All participants followed an evolutionary path towards implementing onsite 3D printing technology. The participants described implementing 3D printing in stages. They gradually increased their array of applications like surgical guides, then temporary dentures, interim crowns, and then final crowns and dentures. P1 gave an example following an evolutionary path:

> Yeah, it was doing surgical guides. So we were using the technology and to design, and then we just came to the realization we could be doing much more

> efficient and bring our costs down if we bring in the in-house printing. And that's what we did. We moved from surgical guides to interim crowns, temporary dentures, and surgical models. We are now moving towards 3D printing final crowns. It [3D printing for final crowns] just got approved a very short while ago. And that's part of the system that we're implementing in two weeks. So this will be used at our practice. It'll be used initially as kind of like an interim crown where let's say you have a tooth that's broken and you're not quite sure whether or not maybe might need a root canal in the future, may not. Instead of going to a final definitive crown, we'll be printing these interim crowns. Now they're approved for final use, but because they're so new, we're going to be a little bit judicious in how we use it, and we're going to use an interim crown.

All the participants were innovators or early adopters of dental 3D printing. However, when implementing this enabling technology strategy, some took a conservative approach. P1 and P4 followed a more conservative approach to onsite dental 3D printing implementation. P1 liked to wait for new technology to be proven before they implemented it in their office. P1 elaborated on their continued conservative approach to onsite 3D printing:

> We’ve always been early adopters, but we're not on the, what I would say, the bleeding edge, where the people on the bleeding edge are the ones like clearing the trails. We're a little further behind them. And that's where we found our sweet spot, where we can really figure out what's really working in the marketplace and then adopt those as our own and develop our own workflows. An example is our

> approach to final crowns. So what we're doing is we're waiting for a little bit of the dust to settle. Oh yeah. Because while we love being out in front with technology, we've found that the people that are first in line, they're the ones that really, really, really are taking a lot of hits with a lot of problems. And we've looked to avoid some of that. Well, I mean, our top typical workflow is we wait for a good six months to a year for everything to kind of settle in. We go in. So we're kind of like, we don't necessarily consider ourselves the pioneers. We're more the settlers. And that's the next level that we're working on now where we just ordered a whole new system by Sprint Ray that will allow us to print out a set of teeth that is a really, really strong material, much stronger than we currently have.

The conservative approach was also followed by P4. In the past, P4 was too aggressive with new technology, and this approach caused problems. P4 highlighted a cautious implementation approach for 3D printing while describing the failure of following an aggressive approach to a previous technology:

> For final crowns, I'm not sure I'm going to jump on board with that quite yet. We'll let some other people test the water on it because you don't want hundreds of those things out there to find out that they're not quite good enough. That's a fear. And that's happened with other materials in the past. They're always coming out with something bigger and better and sometimes it seems really cool. And then you find out, as I found out with hybrid ceramics that you mill, that it ain't

> that good and you end up within a few years you feel like you've replaced them all.

On the other hand, others took a more aggressive approach to implementing their enabling technology strategy. P2, P3, and P5 followed a more aggressive approach to onsite 3D printing implementation enabled by the backing of a corporation and hospital system. P2 said,

> We've 3D printed since we started this, which was about a year and a half ago, over 50,000 digital dentures. And we probably have done the most in the world, I would say, from an enterprise perspective and one single company, there's about 1,000,000 million digital dentures done world globally. But when you think of one enterprise doing 50,000 at only 20% of our network, because we have 1100 offices, we're only doing full digital in about one in 50.

The enabling technology strategy included ensuring that adequate technical support was available to operate and maintain the equipment. The participants' approach to address equipment operation and maintenance differed due to organizational differences. The private practices of P1 and P4 relied on the onsite expertise of the practitioners to perform design, operate, and maintain the equipment. P1 hired an experienced dentist with unique technical expertise to support the equipment. The approach P4 followed differed as he was the only person at the practice with 3D printing expertise. P4 decided which applications would benefit most with his time to use for 3D printing. P4's approach limited the usage of onsite 3D printing because he was the primary practitioner and there was a balance where he appropriated his time for maximum benefit. Conversely, P2, P3, and P5 had dedicated personnel to maintain and operate the equipment.

Theme 2: Innovative Business Model Strategy

An innovative business model strategy refers to core strategies and business processes that ensure profitability or financial returns from incorporating the enabling technology. The participants used innovative business model strategies to maximize positive business impacts using onsite dental 3D printing. All the participants focused on improving key operational metrics such as reduced turnaround time, reduced chair time, and fewer patient visits to complete procedures. These metrics all relate to business costs.

All the participants cited the advantages of reduced chair time, reduced visits, and reduced material costs as part of their innovative business strategy. P1 described the business impact: “So it's really cut down the number of visits, time between visits dramatically and greatly reduced our costs.” P2 also focused on reduced chair time and higher volume at a lower cost to drive the business strategy. P2 quantified chair time: “$500 an hour of chair time. Whereas if I could deliver 75% of the time, and if you talk at scale at 500,000 dentures, how much chair time did I just free up millions and millions of dollars?” P3 also stated that “advantages include fewer visits, better patient experience, and cost reduction due to lower overall material costs and reduced chair time.” P4 expressed a similar sentiment: “Reducing the number of visits, you're reducing chair time, which allows you to see more patients. So you're going to make it up in volume and the cost is less.” P5 added a similar comment: “The onsite definitely offers you the ability to reduce your time, reduce your chair time, reduce the number of visits, and give the patient a better experience."

The participants used different approaches when implementing their business model strategy. P2's company approach focused on a larger scale than the other participants. P2 explained their innovative business model strategy for reducing turnaround time, reducing chair time with fewer visits for final dentures:

> So fast forward to today, what we're doing is our new dentures in days patient promise project. And what this looks like is if you come in the same day, so you come in for a denture before 10 o'clock, we could scan that. We send that to our digital design network, which we've propped up 150 dental technicians into world class digital designers to send back your scan with a finished denture file in two hours. You 3D print that in the office and you could insert that to the patient that day in the afternoon or the next day if they so choose to come in that quickly. And the other thing is we've also propped up our own centralized manufacturing center to support dark offices. So offices that don't have a lab tech. So even if you don't have a printer or your lab tech quits, we have a centralized manufacturing center that can still support same day or next day turnaround time until we reach our final goal of 3D printers in all locations.

One common innovative business model strategy that all the participants embraced for reducing turnaround time was using equipment onsite. Eliminating the lead time required for offsite labs reduced turnaround time. P5 spoke about outside lab limitations and how having the lab onsite decreases time to get an appliance:

> So in fact if you are completely dependent on the lab, it will depend how fast the lab can turn over the case and give it back to you because they sometimes have a backlog and they have a lack of technicians. You also must deal with delivery times. If you have the necessary resources, if you have a technician that is able to print out of your software treatment planning, then you can have it onsite within the same facility and you don't have to wait all that time.

All the participants followed different approaches to implementing the business strategy. P2 focused on a deployment plan that takes advantage of the size of their organization and resource availability. P2’s company innovative business model strategy includes having 3D printers in all their offices however they are currently at only 20% deployment. The company is using a progressive approach until all centers have onsite 3D printers. The individual offices are supported by a central facility staffed with experienced design technicians with the ability to also support offices without printers.

Theme 3: Customer Demand Strategy

Customer demand strategy theme comprises strategies focusing on ensuring the adoption of the enabling technology has positive effects on customers' experience and satisfaction. The participants aimed to optimize positive customer impacts using onsite dental 3D printing. All the participants evaluated the potential positive impacts on the customer when using onsite 3D printing. The customer demand strategy the participants focused on improving patient satisfaction, by ensuring better patient experiences with less chair time, fewer visits, and more access to care. P2 spoke about how patient satisfaction plays a major role in their customer demand strategy:

> So if you think of patients getting access to care, that's always been our number one focus is access to care, better care, start now, start today new patients, new patients, new patients, and delivering better dentistry. And digital dentistry is going to afford us the opportunity to do that. Chair time, patient experience, the accuracy, and trueness of the restorations, they fit better, less adjustments. The advantages if the patient loses it. We can replace it at any of our locations across the country. I mean, there's so much value in that. And it's all done in the office, all the printings done in office, and instead of these prototypes that everybody's doing, we decided to get away from that because we were finding in our early stages that 75% of the patients were happy with their prototypes. So we came to the philosophy of, so 75% of the time we're hitting the mark, why not just deliver that as a final denture? And if 25% of the time they don't like it, that's okay, we're going to reprint it for a nominal cost, right? And now with how well trained our doctors are through coming, how much better our design network's getting and how much better our 3D printing accuracy and trueness in the technology is in this pilot we're doing, we're at 96% success rate at delivery.

The other participants followed a different approach than P2 when treating patients which also had a positive impact on customer demand. The other participants did not print final dentures, but their approach still resulted in positive patient experience. P1 elaborated on the iterative onsite 3D printing process they use for temporary dentures that reduces the discomfort and time for the patient:

> So we print out our temporary dentures that we use that people will wear or will use in the form of a tray. So for example, if we have someone coming in that's going to lose a lot of teeth and maybe on a whole arch and say the upper arch would be an example, maybe they have currently maybe six or seven or eight teeth left in their mouth, we will design a full set of teeth, a denture for the top, and we'll remove the teeth. And then we'll put that denture, which is basically a 3D printed prototype, and we put that directly in the mouth and it becomes a healing denture, and it's what they're wearing while they're healing. So if we determine the teeth look too big or they're too small or they're too long, or they're too short or they're not in the exact position that we really would like to see it, we use input from the patient with that. So the patients have a chance to go home. A spouse may look at it and say, oh, these teeth are too big, or whatever it might be. And then we can make changes in the design and then print out those changes in the form of another printed denture. Well, yeah. I think that the, that's what all the printing does, is it allows you to quickly make changes and then print out another version instead of the laborious task of resetting teeth and wax. And the turnaround time for that is just too slow. Whereas when we're doing these changes, we can modify them on the fly and really print and then try them again the next day.

The other independent dentist followed a similar approach to enhance the patient experience with 3D printed temporary dentures. P4's approach still focused on temporary dentures with the patient having a solution the same day while permanent dentures were in process. P4 explained,

> But just a lot of prototypes, prototypes of dentures and you can print it fast. I mean I can prep a patient's front six teeth and quickly design something and 3D print it and have 'em and use 'em as temporaries and just have that wow effect to where the patient leaves looking almost as good as they're going to look in the final restoration sometimes better. So, and the speed that goes along with the 3D printing now is allows us to do stuff while the patient's still on the chair.

Another example of enhancing the patient's experience involves printing surgical guides. The ability to 3D print a surgical guide onsite reduced turnaround time and allowed the patient a better experience. P2 elaborated on the concept of onsite printed surgical guides reducing total treatment time:

> And then surgical guide patient comes in with an abscess tooth. It's like, Hey, I want an implant, I want it now. I'm off work this week. Or they just commit to treatments. It's like, Hey, we got a spot tomorrow at nine o'clock. Yep, I'll be there. Instead of, well, I got to send this to the planning service and I have to get back to you, and I have to bring you back. And you're three weeks to six weeks later to deliver a single tooth implant.

Another area of dentistry where 3D printing is making positive patient impacts involves cosmetic dentistry. Cosmetic dentistry can have a major impact on a patient's smile and overall self esteem. P1 described the new process for creating veneers in cosmetic dentistry and how 3D printing allows the patient to better visualize the result before committing to the investment. P1 elaborated on instant patient feedback for veneers and cosmetic dentistry contributing to overall patient satisfaction:

> Cosmetic dentistry is where we make a lot of changes in people's smiles and can really change a life through just their aesthetics and their smile. And a lot of people have ideas about how their smile could look, but they really don't. They have a hard time visioning it. In the past we've used photography to take pictures of people's smiles and then imaging software to make the kind of image what we think it would look like. But what 3D printing is doing now is, what we're using is we are making changes in the software on the computer. So that's a really big deal because by using the 3D printed models, not only can we demonstrate what it looks like in their hand where they can hold it, but now for the first time, we can use this injection molding and just hand them a mirror and show them how the teeth are going to actually look in their mouth. Oh, wow. So that's a really big advancement. And that would not be possible unless we were able to make those changes first in the software and then print that out and then create a prototype in their mouth. So we're doing that more and more, and patients are loving the instant feedback they get.

The participants also talked about providing more cost-effective dental solutions with 3D printing. P1 and P2 were committed to providing more cost-effective treatment with the advances in digital dentistry satisfying customer demand. P1 spoke about providing access to dental care for people who would not normally be able to afford fixing their teeth:

> So for these implant patients that are out there that really need desperately need more affordable options, my view, this is the way that's going to take us there. And so I have colleagues that are actually, instead of going to a final set of teeth, which typically the costs of these, for example, a full set of teeth that's made by a dental laboratory, the range in pricing and that you pay as a dentist can be anywhere from $3,000 to $6,000 lab costs. And typically the patient costs is going to be maybe two and a half to three times that. So by really reducing the cost of the final restoration, and by improvements in material science, I think there's an opportunity here to get the dental costs down to probably less than a hundred dollars for a final set of teeth. And if we can drive those costs down, then all those savings get passed down to the patient, and it becomes much more affordable for people that are suffering without teeth. They would love to have teeth but can't afford it. And that's part of what we're doing with all this innovation to try and drive costs down. Yeah. So I mean, all those innovations there have led us to where we are today. And what I believe is going to happen is some of this 3D printing is going to be able to allow dentists to offer more value, a value line of teeth for patients and make that care accessible in ways that never were even manageable before. And that's what this whole thing is about, trying to make care more affordable for people and still not give up much on the quality.

The customer demand strategy theme demonstrated that having a positive impact on the patient’s experiences was an essential consideration in the leaders’ approach to onsite 3D printing. P1 focused on reducing costs and providing dental care to a subset of people that normally would not have access. P2 talked about providing dental solutions to patients at a much faster rate than conventional minimizing the amount of discomfort experienced by the patient. P3 spoke about the patients learning about 3D printing while experiencing the benefits and communicating these positive effects to other patients. The customer demand strategy was a primary motivator for the participants to implement onsite 3D printing.

Connection to Conceptual Framework

The study findings are connected to the DIT conceptual framework because the themes identified are parallel to the central constructs of the theory. One of Christensen's (1997a) constructs of DIT is an enabling technology. The enabling technology strategy theme is evident in my findings as all the participants followed an enabling technology strategy when implementing onsite 3D printing. A second construct of Christensen's theory focused on an innovative business model. Another emerging theme in my findings was an innovative business model strategy where all the participants ensured the use of 3D printing had a positive financial impact on their businesses. A third construct of Christensen's theory describes a consumer demand influence. The findings revealed a customer demand influence strategy theme that all the participants embraced as a central driver to using onsite 3D printing.

Connection to Literature

The enabling technology strategy theme identified and described in this study is congruent with other theories found in the literature. Schumpeter (1942) described how new technologies have the potential to revolutionize manufacturing processes within an industry in the theory of creative destruction. The evolutionary nature of creative destruction is essential in creating new products, processes, and markets (Schumpeter, 1942). The findings in this study, parallel the evolutionary adoption of onsite dental 3D printing by the participants. Rogers (1995) described the adoption of new technologies in his diffusion of innovation theory. Rogers (1995) provided social system member classification based on innovativeness, including innovators, early adopters, early majority, late majority, and laggards where 16% of a population could be considered innovators and early adopters. This is consistent with the findings as the participants identified themselves as innovators and early adopters. A recent survey reinforces this concept with only 17% of dentists currently having a 3D printer in their practice (Revilla-León et al., 2023). The enabling technology strategy theme is also congruent with both the technology acceptance model (TAM) and unified theory of acceptance and use of technology (UTAUT). TAM and UTAUT have been broadly adopted as a means of predicting technology acceptance and usage (Ammenwerth, 2019). The findings for the enabling technology strategy theme showed the participants followed different paths in accepting dental 3D printing. The enabling technology strategy theme requires training and awareness for firms to be successful which was reinforced by Acharya et al. (2023) that noted workshops and education in the dental community should be provided to enable practices to adopt a viable technology enabling strategy for dental 3D printing.

The innovative business model and consumer demand influence strategy themes identified and described in this study are also congruent with the theory of creative destruction. Schumpeter (1942) described how innovation can drive economic growth in the theory of creative destruction. This concept parallels with the findings where the participants enhanced the positive business impact when implementing the business model strategy theme for onsite 3D printing. Schumpeter also described the positive impact innovations can have on overall public welfare. This concept parallels the findings where the participants described how customer demand influence strategy theme was a major decision driver for implementing onsite 3D printing. A recent article highlights the positive customer demand influence of dental onsite 3D printing. Gracco et al. (2023) reinforced the concept that onsite 3D printing will enable practitioners to deliver more accurate, safe, and patient friendly solutions while making dental care more affordable providing greater access to underserved communities.

Applications to Professional Practice

In this study, I found three themes that can be applied to professional practice. When adopting new technologies, business leaders should consider these three themes. The enabling technology strategy theme ensures the technology is effectively incorporated into an operation. Business professionals will need to develop a plan after researching the technology that allows seamless implementation into an organization while addressing the education, resources and support required for success. The findings showed that the participants followed an evolutionary path while addressing the requirements for implementation.

The innovative business model strategy theme addresses how business professionals consider adapting their business models to embrace the new technology while increasing positive business impacts. In the findings, the participants embraced different strategies to maximize the positive impacts on the business model by focusing on decreasing costs and increasing throughput. The customer demand strategy theme focuses on the influence customers have on business professionals when making decisions on implementing technology. The participants all focused on improving the customer experience while providing access to groups that may not be able to benefit from the technology.

However, business professionals cannot consider these themes independently. When considering the technology, the leaders must also consider the business impacts and the customer experience. The participants focus on improved experience through reduced chair time and reduced visits impacted both the business model and the customer experience. The leaders should consider an overall synergistic approach by integrating these three areas to determine the optimum overall strategy.

Implications for Social Change

The findings from this study may help dental leaders conceptualize and plan an effective onsite 3D printing implementation strategy. The leaders can use the findings to facilitate the adoption of onsite dental 3D printing which can contribute to lower dental costs, allowing access to the underserved, and improving the quality of dental care. The lower cost will allow underserved communities that are in desperate need of dental care options to improve their ability to receive quality care. With the aging population and many that lack dental insurance, dental 3D printing may provide the avenue to receive this care. Another potential is creating specialized jobs to support dental 3D printing that has the potential for economic contributions to society.

Recommendations for Action

Dental center leaders need to develop a 3D printing strategy to support an implementation plan. A business analysis needs to be executed along with the potential downside if the leaders do not embrace dental 3D printing. Investment, profits, and operating costs all require consideration. As the recent literature suggests, forums and workshops for collecting and exchanging information and skills relevant to digital dentistry and 3D printing should be provided to aid dental center leaders' implementation strategy development.

Recommendations for Further Research

The limitation of participants willing to participate made it difficult to get a robust cross section of practitioners. Future researchers could focus on 3D printing as it applies to each specialty of dentistry. Future researchers could focus on 3D dental applications for endodontists, orthodontists, periodontists, prosthodontists, pediatric dentists, and oral and maxillofacial surgeons. Future researchers could also analyze the different business types that impact dental 3D printing strategies. The strategy differences between single offices, members of a hospital system, a private network, or a DSO could be highlighted by future researchers.

Reflections

The DBA Doctoral Study process has been a journey. One of the most important lessons was to be humble and accept criticism as constructive. This is easier said than done with personal bias about the quality of my work. It was early in the journey that I made this realization and I must be diligent as I continue to focus on the positive aspects of constructive criticism.

Conclusion

The challenge of implementing a successful strategy that addresses a dynamic process that is revolutionizing an industry cannot be underestimated. Failing to be proactive may mean your business will be disrupted with a difficult prospect of recovering.

References

Abdulhameed, O., Al-Ahmari, A., Ameen, W., & Mian, S. H. (2019). Additive manufacturing: Challenges, trends, and applications. *Advances in Mechanical Engineering*, *11*(2), 1-27. https://doi.org/10.1177/1687814018822880

Acharya, A., Chodankar, R. N., Patil, R., & Patil, A. G. (2023). Assessment of knowledge, awareness, and practices toward the use of 3D printing in dentistry among dental practitioners and dental technicians: A cross-sectional study. *Journal of Oral Biology and Craniofacial Research*, *13*(2), 253–258. https://doi.org/10.1016/j.jobcr.2023.02.001

Ahmad, S., Hasan, N., Fauziya, Gupta, A., Nadaf, A., Ahmad, L., Aqil, M., & Kesharwani, P. (2022). Review on 3D printing in dentistry: Conventional to personalized dental care. *Journal of Biomaterials Science -- Polymer Edition*, *33*(17), 2292–2323. https://doi.org/10.1080/09205063.2022.2099666

Ahmad, S., Wasim, S., Irfan, S., Gogoi, S., Srivastava, A., & Farheen, Z. (2019). Qualitative v/s. quantitative research--A summarized review. *Journal of Evidence Based Medicine and Healthcare*, *6*(43), 2828–2832. http://doi.org/10.18410/jebmh/2019/587

Aimar, A., Palermo, A., & Innocenti, B. (2019). The role of 3D printing in medical applications: A state of the art. *Journal of Healthcare Engineering*, *2019*, 1-10. http://doi.org/10.1155/2019/5340616

Akinyode, B. F., & Khan, T. H. (2018). Step by step approach for qualitative data analysis. *International Journal of Built Environment and Sustainability*, *5*(3), 163-

174. https://doi.org/10.11113/ijbes.v5.n3.267

Akyalcin, S., Rutkowski, P., Arrigo, M., Trotman, C. A., & Kasper, F. K. (2021). Evaluation of current additive manufacturing systems for orthodontic 3-dimensional printing. *American Journal of Orthodontics & Dentofacial Orthopedics*, *160*(4), 594–602. https://doi.org/10.1016/j.ajodo.2020.12.022

Alageel, O. (2022). Three-dimensional printing technologies for dental prosthesis: A review. *Rapid Prototyping Journal*, *28*(9), 1764–1778. https://doi.org/10.1108/RPJ-07-2021-0164

Alam, M. K. (2020). A systematic qualitative case study: Questions, data collection, NVivo analysis and saturation. *Qualitative Research in Organizations and Management: An International Journal*, *16*(1), 1–31. https://doi.org/10.1108/QROM-09-2019-1825

Alpi, K. M., & Evans, J. J. (2019). Distinguishing case study as a research method from case reports as a publication type. *Journal of the Medical Library Association*, *107*(1), 1–5. https://doi.org/10.5195/jmla.2019.615

Ammenwerth, E. (2019). Technology acceptance models in health informatics: TAM and UTAUT. *Studies in Health Technology and Informatics*, *263*, 64–71. https://doi.org/10.3233/SHTI190111

Andreassen, P., Christensen, M. K., & Møller, J. E. (2020). Focused ethnography as an approach in medical education research. *Medical Education*, *54*(4), 296–302. https://doi.org/10.1111/medu.14045

Andrews, A. P. (2020). Volatility and persistence in the automobile industry: Persistence as a signal of brand loyalty. *Competition Forum*, *18*(1/2), 80–96.

Anggasta, A. G., & Kusumawardhani, A. (2021). Analysis of disruptive innovation implementation strategy. *International Journal of Economics, Business and Accounting Research*, *5*(4), 519-526.

Anney, V. N. (2014). Ensuring the quality of the findings of qualitative research: Looking at trustworthiness criteria. *Journal of Emerging Trends in Educational Research and Policy Studies*, *5*(2), 272-281.

Barrett, D., & Twycross, A. (2018). Data collection in qualitative research. *Evidence-Based Nursing*, *21*(3), 63–64. https://doi.org/10.1136/eb-2018-102939

Beausoleil, A. M. (2018). Revisiting Rogers: The diffusion of his innovation development process as a normative framework for innovation managers, students and scholars. *Journal of Innovation Management*, *6*(4), 73-97. https://doi.org/10.24840/2183-0606_006.004_0006

Beltagui, A., Rosli, A., & Candi, M. (2020). Exaptation in a digital innovation ecosystem: The disruptive impacts of 3D printing. *Research Policy*, *49*(1), 1-16. https://doi.org/10.1016/j.respol.2019.103833

Bentson, C., & Copple, D. (2022). Opportunities in the evolving orthodontic industry–Digital processes, teledentistry and group practices. *Seminars in Orthodontics*, *28*(1), 37–42. https://doi.org/10.1053/j.sodo.2022.02.008

Berman, B. (2020). Managing the disruptive effects of 3D printing. *Rutgers Business Review*, *5*(3), 294-309.

Boland, J., Banks, S., Krabbe, R., Lawrence, S., Murray, T., Henning, T., & Vandenberg,

M. (2021). A COVID-19-era rapid review: Using Zoom and Skype for qualitative group research. *Public Health Research & Practice*, *32*(2), 1-9. https://doi.org/10.17061/phrp31232112

Busetto, L., Wick, W., & Gumbinger, C. (2020). How to use and assess qualitative research methods. *Neurological Research and Practice*, *2*(1), 1-10. https://doi.org/10.1186/s42466-020-00059-z

Bush, A. A., & Amechi, M. H. (2019). Conducting and presenting qualitative research in pharmacy education. *Currents in Pharmacy Teaching and Learning*, *11*(6), 638–650. https://doi.org/10.1016/j.cptl.2019.02.030

Campbell, S., Greenwood, M., Prior, S., Shearer, T., Walkem, K., Young, S., Bywaters, D., & Walker, K. (2020). Purposive sampling: Complex or simple? Research case examples. *Journal of Research in Nursing*, *25*(8), 652–661. https://doi.org/10.1177/1744987120927206

Castleberry, A., & Nolen, A. (2018). Thematic analysis of qualitative research data: Is it as easy as it sounds? *Currents in Pharmacy Teaching and Learning*, *10*(6), 807–815. https://doi.org/10.1016/j.cptl.2018.03.019

Chakraborty, C., Madhuri, G., Sharma, N., Ranjan, S., Ade, S., & Pusa, D. (2021). Glimpse of 3D printing in dentistry: A review. *Journal of Advanced Medical and Dental Sciences Research*, *9*(6), 127-130. https://doi.org/10.21276/jamdsr

Chiu, M. C., & Chen, T. C. T. (2022). A ubiquitous healthcare system of 3D printing facilities for making dentures: Application of type-II fuzzy logic. *Digital Health*, *8*, 1-12. https://doi.org/10.1177/20552076221092540

Christensen, C. (1997a). *The innovator's dilemma: When new technologies cause great firms to fail*. Harvard Business Review Press.

Christensen, C. (1997b). Patterns in the evolution on product competition. *European Management Journal*, *15*(2), 117-127. http://doi.org/10.1016/S0263-2373(96)00081-3

Christensen, C., McDonald, R., Altman, E. J., & Palmer, J. E. (2018). Disruptive innovation: An intellectual history and directions for future research. *Journal of Management Studies*, *55*(7), 1043-1078. http://doi.org/10.1111/joms.12349

Christensen, C., & Raynor, M. E. (2003). *The innovator's solution: Creating and sustaining successful growth*. Harvard Business Review Press.

Clark, K. R., & Vealé, B. L. (2018). Strategies to enhance data collection and analysis in qualitative research. *Radiologic Technology*, *89*(5), 482CT–485CT.

Cunha, T. D. M. A. D., Barbosa, I. D. S., & Palma, K. K. (2021). Orthodontic digital workflow: Devices and clinical applications. *Dental Press Journal of Orthodontics*, *26*(6), 1-34. https://doi.org/10.1590/2177-6709.26.6.e21spe6

da Costa, L. P. G., Zamalloa, S. I. D., Alves, F. A. M., Spigolon, R., Mano, L. Y., Costa, C., & Mazzo, A. (2021). 3D printers in dentistry: A review of additive manufacturing techniques and materials. *Clinical and Laboratorial Research in Dentistry*, *2021*, 1-10. https://doi.org/10.11606/issn.2357-8041.clrd.2019.188502

Dearing, J. W., & Cox, J. G. (2018). Diffusion of innovations theory, principles, and practice. *Health Affairs*, *37*(2), 183-190. https://doi.org/10.1377/hlthaff.2017.1104

DeJonckheere, M., & Vaughn, L. M. (2019). Semistructured interviewing in primary care research: A balance of relationship and rigour. *Family Medicine and Community Health*, *7*(2), 1-8. https://doi.org/10.1136/fmch-2018-000057

Delic, M., & Eyers, D. R. (2020). The effect of additive manufacturing adoption on supply chain flexibility and performance: An empirical analysis from the automotive industry. *International Journal of Production Economics*, *228*, 1-15. https://doi.org/10.1016/j.ijpe.2020.107689

Delic, M., Eyers, D. R., & Mikulic, J. (2019). Additive manufacturing: Empirical evidence for supply chain integration and performance from the automotive industry. *Supply Chain Management: An International Journal*, *24*(5), 604–621. https://doi.org/10.1108/SCM-12-2017-0406

Demiralp, E., Dogru, G., & Yilmaz, H. (2021). Additive manufacturing (3D printing) methods and applications in dentistry. *Clinical and Experimental Health Sciences*, *11*(1), 182-190. https://doi.org/10.33808/clinexphealthsci.786018

Dennies, D. P. (2021). Critical thinking in the application of additive manufacturing processes: A review. *Journal of Failure Analysis and Prevention*, *21*(4), 1099-1125. https://doi.org/10.1007/s11668-021-01175-x

Denning, S. (2016). Christensen updates disruption theory. *Strategy & Leadership*. *44*(2), 10-16. http://doi.org/10.1108/SL-01-2016-0005

Ding, J., Baumers, M., Clark, E. A., & Wildman, R. D. (2021). The economics of additive manufacturing: Towards a general cost model including process failure. *International Journal of Production Economics*, *237*, 1-12. https://doi.org/10.1016/j.ijpe.2021.108087

Dogru, T., Mody, M., & Suess, C. (2019). Adding evidence to the debate: Quantifying Airbnb's disruptive impact on ten key hotel markets. *Tourism Management*, *72*, 27-38. https://doi.org/10.1016/j.tourman.2018.11.008

Doyle, L., McCabe, C., Keogh, B., Brady, A., & McCann, M. (2020). An overview of the qualitative descriptive design within nursing research. *Journal of Research in Nursing : JRN*, *25*(5), 443–455. https://doi.org/10.1177/1744987119880234

Ergul Sonmez, E., & Koc, M. (2018). Pre-service teachers' lived experiences with taking courses through learning management systems: A qualitative study. *Turkish Online Journal of Distance Education*, *19*(2), 101–116. http://doi.org/10.17718/tojde.415823

Fan, D., Li, Y., Wang, X., Zhu, T., Wang, Q., Cai, H., Li, W., Tian, Y., & Liu, Z. (2020). Progressive 3D printing technology and its application in medical materials. *Frontiers in Pharmacology*, *11(*122*)*, 1-12. https://doi.org/10.3389/fphar.2020.00122

Francisco, I., Ribeiro, M. P., Marques, F., Travassos, R., Nunes, C., Pereira, F., Caramelo, F., Paula, A. B., & Vale, F. (2022). Application of three-dimensional digital technology in orthodontics: The state of the art. *Biomimetics*, *7*(23), 1-14. https://doi.org/10.3390/biomimetics7010023

Galante, R., Figueiredo-Pina, C. G., & Serro, A. P. (2019). Additive manufacturing of ceramics for dental applications: A review. *Dental Materials*, *35*(6), 825–846. https://doi.org/10.1016/j.dental.2019.02.026

Goss, K. F. (1979). Consequences of diffusion of innovations. *Rural Sociology*, *44*(4), 754–772.

Gracco, A., De Stefani, A., & Bruno, G. (2023). Influence of new technology in dental care: A public health perspective. *International Journal of Environmental Research and Public Health*, *20*(7). https://doi.org/10.3390/ijerph20075364

Guo, J., Pan, J., Guo, J., Gu, F., & Kuusisto, J. (2019). Measurement framework for assessing disruptive innovations. *Technological Forecasting & Social Change*, *139*, 250–265. http://doi.org/10.1016/j.techfore.2018.10.015

Havens, A. E., & Flinn, W. (1975). Green revolution technology and community development: The limits of action programs. *Economic Development & Cultural Change*, *23*(3), 469-481. https://doi.org/10.1086/450809

Ho, J. C. (2021). Disruptive innovation from the perspective of innovation diffusion theory. *Technology Analysis & Strategic Management*, *34*(4), 363–376. https://doi.org/10.1080/09537325.2021.1901873

Houghton, C., Casey, D., Shaw, D., & Murphy, K. (2013). Rigour in qualitative case-study research. *Nurse Researcher*, *20*(4), 12-17. http://doi.org/10.7748/nr2013.03.20.4.12.e326

Huang, G., Wu, L., Hu, J., Zhou, X., He, F., Wan, L., & Pan, S. T. (2022). Main applications and recent research progresses of additive manufacturing in dentistry. *BioMed Research International*, *2022*,1–26. https://doi.org/10.1155/2022/553018

Ishida, Y., Miura, D., Miyasaka, T., & Shinya, A. (2020). Dimensional accuracy of dental casting patterns fabricated using consumer 3D printers. *Polymers*, *12*(10), 1-9.

https://doi.org/10.3390/polym12102244

Jawahar, A., & Maragathavalli, G. (2019). Applications of 3D printing in dentistry–A review. *Journal of Pharmaceutical Sciences and Research*, *11*(5), 1670-1675.

Jemghili, R., Taleb, A. A., & Khalifa, M. (2021). A bibliometric indicators analysis of additive manufacturing research trends from 2010 to 2020. *Rapid Prototyping Journal*, *27*(7), 1432–1454. http://doi.org/10.1108/RPJ-11-2020-0274

Joda, T., Yeung, A. W. K., Hung, K., Zitzmann, N. U., & Bornstein, M. M. (2021). Disruptive innovation in dentistry: What it is and what could be next. *Journal of Dental Research*, *100*(5), 448–453. https://doi.org/10.1177/0022034520978774

Kamali, A. H., Moradi, M., Goodarzian, F., & Ghasemi, P. (2022). A discrete event simulation method for performance analysis of an additive manufacturing in the dental clinic. *The International Journal of Advanced Manufacturing Technology*, *118*(9), 2949-2979. http://doi.org/10.1007/s00170-021-08135-7

Kessler, A., Hickel, R., & Reymus, M. (2020). 3D printing in dentistry—State of the art. *Operative Dentistry*, *45*(1), 30-40. https://doi.org/10.2341/18-229-L

Khalid, M., & Peng, Q. (2021). Sustainability and environmental impact of additive manufacturing: A literature review. *Computer-Aided Design and Applications*, *18*(6), 1210-1232. https://doi.org/10.14733/cadaps.2021.1210-1232

Kihara, H., Sugawara, S., Yokota, J., Takafuji, K., Fukazawa, S., Tamada, A., Hatakeyama, W., & Kondo, H. (2021). Applications of three-dimensional printers in prosthetic dentistry. *Journal of Oral Science*, *63*(3), 212–216. https://doi.org/10.2334/josnusd.21-0072

Kilkki, K., Mäntylä, M., Karhu, K., Hämmäinen, H., & Ailisto, H. (2018). A disruption framework. *Technological Forecasting and Social Change*, *129*, 275-284. https://doi.org/10.1016/j.techfore.2017.09.034

Kim, H. J., Lim, S. W., Lee, M. K., Ju, S. W., Park, S. H., Ahn, J. S., & Hwang, K. G. (2021). Which three-dimensional printing technology can replace conventional manual method of manufacturing oral appliance? A preliminary comparative study of physical and mechanical properties. *Applied Sciences*, *12*(1), 1-12. https://doi.org/10.3390/app12010130

Kleer, R., & Piller, F. T. (2019). Local manufacturing and structural shifts in competition: Market dynamics of additive manufacturing. *International Journal of Production Economics*, *216*, 23–34. https://doi.org/10.1016/j.ijpe.2019.04.019

Komlos, J. (2016). Has Schumpeterian creative destruction become more destructive? *Revista Tiempo & Economía*, *3*(1), 9–18. https://doi.org/10.21789/24222704.1092

Korstjens, I., & Moser, A. (2018). Series: Practical guidance to qualitative research. Part 4: Trustworthiness and publishing. *The European Journal of General Practice*, *24*(1), 120–124. https://doi.org/10.1080/13814788.2017.1375092

Kulkarni, P., Kumar, A., Chate, G., & Dandannavar, P. (2021). Elements of additive manufacturing technology adoption in small-and medium-sized sized companies. *Innovation & Management Review*, *18(*4*)*, 400-416. https://doi.org/10.1108/INMR-02-2020-0015

Kumaraswamy, A., Garud, R., & Ansari, S. (2018). Perspectives on disruptive innovations. *Journal of Management Studies*, *55*(7), 1025-1042. http://doi.org/10.2139/ssrn.3216121

Lee, J. Y., Nagalingam, A. P., & Yeo, S. H. (2021). A review on the state-of-the-art of surface finishing processes and related ISO/ASTM standards for metal additive manufactured components. *Virtual & Physical Prototyping*, *16*(1), 68–96. http://doi.org/10.1080/17452759.2020.1830346

Lincoln, Y. S., & Guba, E. G. (1985). *Naturalistic Inquiry*. Sage.

Liu, X. (2018). Interviewing elites: Methodological issues confronting a novice. *International Journal of Qualitative Methods*, *17*(1), 1-9. https://doi.org/10.1177/1609406918770323

Loges, K., & Tiberius, V. (2022). Implementation challenges of 3D printing in crowns: A ranking-type delphi. *Materials*, *15*(431), 1-10. https://doi.org/10.3390/ma15020431

Lund, B. D., Omame, I., Tijani, S., & Agbaji, D. (2020). Perceptions toward artificial intelligence among academic library employees and alignment with the diffusion of innovations' adopter categories. *College & Research Libraries*, *81*(5), 865–882. https://doi.org/10.5860/crl.81.5.865

Maresch, D., & Gartner, J. (2020). Make disruptive technological change happen - The case of additive manufacturing. *Technological Forecasting & Social Change*, *155*, 1-13. https://doi.org/10.1016/j.techfore.2018.02.009

Martínez-Vergara, S. J., & Valls-Pasola, J. (2020). Clarifying the disruptive innovation puzzle: A critical review. *European Journal of Innovation Management*, *24*(3), 893-918. http://doi.org/10.1108/EJIM-07-2019-0198

McDowall, W. (2018). Disruptive innovation and energy transitions: Is Christensen's theory helpful? *Energy Research & Social Science*, *37*(1), 243–246. http://doi.org/10.1016/j.erss.2017.10.049

Millar, C., Lockett, M., & Ladd, T. (2018). Disruption: Technology, innovation and society. *Technological Forecasting and Social Change*, *129*, 254-260. https://doi.org/10.1016/j.techfore.2017.10.020

Morse, J. M., Barrett, M., Mayan, M., Olson, K., & Spiers, J. (2002). Verification strategies for establishing reliability and validity in qualitative research. *International Journal of Qualitative Methods*, *1*(2), 13–22. https://doi.org/10.1177/160940690200100202

Naidu, T., & Prose, N. (2018). Re-envisioning member checking and communicating results as accountability practice in qualitative research: A South African community-based organization example. *Forum: Qualitative Social Research*, *19*(3), 783–797. https://doi.org/10.17169/fqs-19.3.3153

National Research Council. (2003). Protecting participants and facilitating social and behavioral sciences research. National Academies Press. https://tethys.pnnl.gov/organization/national-research-council-national-academies-nrc

Neubauer, B. E., Witkop, C. T., & Varpio, L. (2019). How phenomenology can help us learn from the experiences of others. *Perspectives on Medical Education*, *8*(2), 90-97. https://doi.org/ 10.1007/s40037-019-0509-2

Ngozwana, N. (2018). Ethical dilemmas in qualitative research methodology: Researcher's reflections. *International Journal of Educational Methodology, 4*(1), 19–28. http://doi.org/10.12973/ijem.4.1.19

Nicali, A., Pradal, G., Brandolini, G., Mantelli, A., & Levi, M. (2022). Novel 3D printing method to reinforce implant-supported denture fiberglass as material for implant prosthesis: A pilot study. *Clinical and Experimental Dental Research*, *8*(3), 715–720. http://doi.org/10.1002/cre2.568

Noble, H., & Heale, R. (2019). Triangulation in research, with examples. *Evidence-Based Nursing*, *22*(3), 67–68. https://doi.org/10.1136/ebnurs-2019-103145

Noble, H., & Smith, J. (2015). Issues of validity and reliability in qualitative research. *Evidence-Based Nursing*, *18*(2), 34–35. https://doi.org/10.1136/eb-2015-102054

Nowell, L. S., Norris, J. M., White, D. E., & Moules, N. J. (2017). Thematic analysis: Striving to meet the trustworthiness criteria. *International Journal of Qualitative Methods*, *16*(1), 1-13. https://doi.org/10.1177/1609406917733847

Öberg, C., & Shams, T. (2019). On the verge of disruption: Rethinking position and role – The case of additive manufacturing. *Journal of Business & Industrial Marketing*, *34*(5), 1093–1105. http://doi.org/10.1108/JBIM-10-2018-0293

Oberoi, G., Nitsch, S., Edelmayer, M., Janjić, K., Müller, A. S., & Agis, H. (2018). 3D printing—Encompassing the facets of dentistry. *Frontiers in Bioengineering and Biotechnology*, *6*(172), 1-13. http://doi.org/10.3389/fbioe.2018.00172

Onwuegbuzie, A. J., & Leech, N. L. (2007). A call for qualitative power analyses. *Quality & Quantity*, *41*(1), 105–121. https://doi.org/10.1007/s11135-005-1098-1

O'Reilly, C., & Binns, A. J. (2019). The three stages of disruptive innovation: Idea generation, incubation, and scaling. *California Management Review*, *61*(3), 49-71. http://doi.org/10.1177/0008125619841878

Paoletti, J., Bisbey, T. M., Zajac, S., Waller, M. J., & Salas, E. (2021). Looking to the middle of the qualitative-quantitative spectrum for integrated mixed methods. *Small Group Research*, *52*(6), 1-35, https://doi.org/10.1177/1046496421992433

Pérez, L., Paulino, V. D. S., & Cambra-Fierro, J. (2017). Taking advantage of disruptive innovation through changes in value networks: Insights from the space industry. *Supply Chain Management: An International Journal*, *22*(2), 97–106. http://doi.org/10.1108/SCM-01-2017-0017

Peterson, J. S. (2019). Presenting a qualitative study: A reviewer's perspective. *Gifted Child Quarterly*, *63*(3), 147–158. http://doi.org/10.1177/0016986219844789

Pillai, S., Upadhyay, A., Khayambashi, P., Farooq, I., Sabri, H., Tarar, M., Lee, K. T., Harb, I., Zhou, S., Wang, Y., & Tran, S. D. (2021). Dental 3D-printing: Transferring art from the laboratories to the clinics. *Polymers*, *13*(1), 1-25. https://doi.org/ 10.3390/polym13010157

Prasad, S., Nourah, A. K., Sujatha, G., Raj, T., & Patil, S. (2018). 3D printing in dentistry. *Journal of 3D Printing in Medicine, 2*(3), 89–91. https://doi.org/10.2217/3dp-2018-0012

Redman, B. K., & Caplan, A. L. (2021). Should the regulation of research misconduct be integrated with the ethics framework promulgated in The Belmont Report? *Ethics & Human Research*, *43*(1), 37–41. https://doi.org/10.1002/eahr.500078

Rekow, E. D. (2020). Digital dentistry: The new state of the art -Is it disruptive or destructive? *Dental Materials*, *36*(1), 9–24. http://doi.org/10.1016/j.dental.2019.08.103

Renjith, V., Yesodharan, R., Noronha, J. A., Ladd, E., & George, A. (2021). Qualitative methods in health care research. *International Journal of Preventive Medicine*, *12*(2), 1–7. https://doi.org/10.4103/ijpvm.IJPVM_321_19

Revilla-León, M., Frazier, K., da Costa, J., Haraszthy, V., Ioannidou, E., MacDonnell, W., Park, J., Tenuta, L. M. A., Eldridge, L., Vinh, R., & Kumar, P. (2023). Prevalence and applications of 3-dimensional printers in dental practice: An American Dental Association clinical evaluators panel survey. *The Journal of the American Dental Association*, *154*(4), 355-356.

Rogers, E. (1995). *Diffusion of Innovations.* (4th ed.). The Free Press.

Roller, M. R., & Lavrakas, P. J. (2018). A total quality framework approach to sharing qualitative research data: Comment on Dubois et al (2018). *Qualitative Psychology*, *5*(3), 394–401. https://doi.org/10.1037/qup0000081

Róth, I., Czigola, A., Fehér, D., Vitai, V., Joós-Kovács, G. L., Hermann, P., Borbély, J., & Vecsei, B. (2022). Digital intraoral scanner devices: A validation study based on common evaluation criteria. *BMC Oral Health*, *22*(1), 1–17. https://doi.org/10.1186/s12903-022-02176-4

Rouf, S., Malik, A., Singh, N., Raina, A., Naveed, N., Siddiqui, M. I. H., & Haq, M. I. U. (2022). Additive manufacturing technologies: Industrial and medical applications. *Sustainable Operations and Computers*, *3*, 258–274. https://doi.org/10.1016/j.susoc.2022.05.001

Roy, K., Zvonkovic, A., Goldberg, A., Sharp, E., & LaRossa, R. (2015). Sampling richness and qualitative integrity: Challenges for research with families. *Journal of Marriage and Family*, *77*(1), 243-260. https://doi.org/10.1111/jomf.12147

Rutberg, S., & Bouikidis, C. D. (2018). Focusing on the fundamentals: A simplistic differentiation between qualitative and quantitative research. *Nephrology Nursing Journal*, *45*(2), 209–213.

Sadiq, F., Hussain, T., & Naseem, A. (2020). Managers' disruptive innovation activities: The construct, measurement and validity. *Management Decision*, *59*(2), 153–174. https://doi.org/10.1108/MD-08-2019-1047

Salmi, M. (2021). Additive manufacturing processes in medical applications. *Materials*, *14*(1), 191-206. https://doi.org/10.3390/ma14010191

Sampere, J. P. V., Bienenstock, M. J., & Zuckerman, E. W. (2016). Debating disruptive innovation. *MIT Sloan Management Review*, *57*(3), 26-30.

Schmidt, A. L., & Scaringella, L. (2020). Uncovering disruptors' business model innovation activities: Evidencing the relationships between dynamic capabilities and value proposition innovation. *Journal of Engineering and Technology Management*, *57*, 1-16 http://doi.org/10.1016/j.jengtecman.2020.101589

Schmidt, A. L., & van der Sijde, P. (2022). Disruption by design? Classification framework for the archetypes of disruptive business models. *R&D Management*, *52*(5), 893-929. http://doi.org/10.1111/radm.12530

Schumpeter, J. A. (1942). *Capitalism, socialism and democracy*. Harper.

Schweiger, J., Edelhoff, D., Güth, J. F., & Joda, T. (2021). 3D printing in digital prosthetic dentistry: An overview of recent developments in additive manufacturing. *Journal of Clinical Medicine*, *10*(9), 1-24. http://doi.org/10.3390/jcm10092010

Shaikh, S., Nahar, P., & Ali, H. M. (2021). Current perspectives of 3d printing in dental applications. *Brazilian Dental Science*, *24*(3).1-9. https://doi.org/10.14295/bds.2021.v24i3.2481

Shannon, T., & Groth, C. (2021). Be your own manufacturer: 3D printing intraoral appliances. *Seminars in Orthodontics*, *27*(3), 184–188. https://doi.org/10.1053/j.sodo.2021.09.004

Si, S., & Chen, H. (2020). A literature review of disruptive innovation: What it is, how it works and where it goes. *Journal of Engineering and Technology Management*, *56*, 1-21. https://doi.org/10.1016/j.jengtecman.2020.101568

Si, S., Hall, J., Suddaby, R., Ahlstrom, D., & Wei, J. (2022). Technology, entrepreneurship, innovation and social change in digital economics. *Technovation*, *119* (2023), 1-10. https://doi.org/10.1016/j.technovation.2022.102484

Sim, J., Saunders, B., Waterfield, J., & Kingstone, T. (2018). Can sample size in qualitative research be determined a priori? *International Journal of Social*

Research Methodology, *21*(5), 619–634. https://doi.org/10.1080/13645579.2018.1454643

Singh, S., Dhawan, P., & Nautiyal, M. (2022). Application of rapid prototyping in prosthodontics. *Frontiers in Biomedical Technologies*, *9*(3), 237–245. https://doi.org/10.18502/fbt.v9i3.9651

Spencer, A., & Kirchhoff, B. (2006). Schumpeter and new technology based firms: Towards a framework for how NTBFs cause creative destruction. *International Entrepreneurship & Management Journal*, *2*(2), 145–156. https://doi.org/10.1007/s11365-006-8681-3

Steenhuis, H. J., & Pretorius, L. (2017). The additive manufacturing innovation: A range of implications. *Journal of Manufacturing Technology Management*, *28*(1), 122–143. http://doi.org/10.1108/JMTM-06-2016-0081

Thakur, R., Al Saleh, D., & Hale, D. (2023). Digital disruption: A managers' eye view. *Journal of Business & Industrial Marketing*. *38*(1), 53–70. https://doi.org/10.1108/JBIM-05-2021-0273

Theofanidis, D., & Fountouki, A. (2018). Limitations and delimitations in the research process. *Perioperative Nursing*, *7*(3), 155–163. http://doi.org/10.5281/zenodo.2552022

Tian, Y., Chen, C., Xu, X., Wang, J., Hou, X., Li, K., Lu, X., Shi, H., Lee, E. S., & Jiang, H. B. (2021). A review of 3D printing in dentistry: Technologies, affecting factors, and applications. *Scanning*, *2021*(1), 1–19. https://doi.org/10.1155/2021/9950131

Tomaszewski, L. E., Zarestky, J., & Gonzalez, E. (2020). Planning qualitative research: Design and decision making for new researchers. *International Journal of Qualitative Methods, 19*, 1-7. https://doi.org/10.1177/1609406920967174

Turkyilmaz, I., & Wilkins, G. N. (2021). 3D printing in dentistry – Exploring the new horizons. *Journal of Dental Sciences, 16*(3), 1037–1038. http://doi.org/10.1016/j.jds.2021.04.004

U.S. Department of Health and Human Services. (1979). *The Belmont Report. Ethical principles and guidelines for the protection of human subjects of research.* The National Commission for the Protection of Human Subjects of Biomedical and Behavioral Research. https://www.hhs.gov/ohrp/regulations-and-policy/belmont-report/read-the-belmont-report/index.html

Villias, A., Karkazis, H., Yannikakis, S., Artopoulou, I. I., & Polyzois, G. (2022). Is the number of appointments for complete denture fabrication reduced with CAD-CAM? A literature review. *Prosthesis*, *4*(10), 91–101. https://doi.org/10.3390/prosthesis4010010

Wang, C., Fang, Y., & Zhang, C. (2022). Mechanism and countermeasures of “The Innovator’s Dilemma” in business model. *Journal of Innovation & Knowledge*, *7*(2), 1-11. http://doi.org/10.1016/j.jik.2022.100169

Watkins, D. C. (2017). Rapid and rigorous qualitative data analysis: The “RADaR” technique for applied research. *International Journal of Qualitative Methods*, *16*(1), 1-9. http://doi.org/10.1177/1609406917712131

Weller, S. C., Vickers, B., Bernard, H. R., Blackburn, A. M., Borgatti, S., Gravlee, C. C.,

& Johnson, J. C. (2018). Open-ended interview questions and saturation. *PloS One*, *13*(6), 1-18. https://doi.org/10.1371/journal.pone.0198606

Williams, M., & Moser, T. (2019). The art of coding and thematic exploration in qualitative research. *International Management Review*, *15*(1), 45–55.

Yeong, M. L., Ismail, R., Ismail, N. H., & Hamzah, M. (2018). Interview protocol refinement: Fine-tuning qualitative research interview questions for multi-racial populations in Malaysia. *Qualitative Report*, *23*(11), 2700–2713. http://doi.org/10.46743/2160-3715/2018.3412

Yin, R. K. (2009). *Case study research: Design and methods* (4th ed.). Sage.

Yin, R. K. (2018). *Case study research: Design and methods* (6th ed.). Sage.

Yu, W., Dai, S., Liu, F., & Yang, Y. (2022). Matching disruptive innovation paths with entrepreneurial networks: A new perspective on startups' growth with Chinese evidence. *Asian Business & Management*, *2022*, 1-25. https://doi.org/10.1057/s41291-022-00177-3

Yuan, F., Sun, Y., Zhang, L., & Sun, Y. (2019). Accuracy of chair-side fused-deposition modelling for dental applications. *Rapid Prototyping Journal*, *25*(5), 857–863. https://doi.org/10.1108/RPJ-04-2018-0082

Appendix A: Figure Reprint Permission Letter

Edward Zamanian

From:	no-reply@copyright.com
Sent:	Thursday, August 4, 2022 5:38 PM
To:	Edward Zamanian
Subject:	Thank you for your order with RightsLink / Elsevier

Thank you for your order!

Dear Edward Zamanian,

Thank you for placing your order through Copyright Clearance Center's RightsLink® service.

Order Summary

Licensee:	Edward Zamanian
Order Date:	Aug 4, 2022
Order Number:	5362130639600
Publication:	Dental Materials
Title:	Additive manufacturing of ceramics for dental applications: A review
Type of Use:	reuse in a thesis/dissertation
Order Ref:	1969
Order Total:	0.00 USD

View or print complete details of your order and the publisher's terms and conditions.

Sincerely,

Copyright Clearance Center

Tel: +1-855-239-3415 / +1-978-646-2777
customercare@copyright.com
https://myaccount.copyright.com

RightsLink

Appendix B: Invitation Letter

Dear Sir/Madam,

My name is Edward Zamanian and I am a doctoral candidate working on completing my Doctor of Business Administration degree at Walden University. As part of my doctoral study research, I would like to invite you to participate in a research study I am conducting to explore strategies that dental center leaders use to improve productivity using onsite 3D printing . Your participation in the research study is voluntary and will be confidential. My timeframe is rather short to complete the study. I am also aware of your time constraints in doing the interview. However, I believe that your participation will make an important contribution to the research and available literature.

Please ask me any questions you may have before accepting the invitation to participate. To achieve the objectives of the research study, your participation depends on satisfying the following eligibility criteria: (a) dental center leaders who have successfully implemented strategies to improve productivity using onsite 3D printing, (b) dental center leaders with a minimum of 5 years in a leadership position, and (c) dental center leaders with a minimum of 2 years clinical experience using 3D printing.

If you satisfy these criteria and agree to participate in the study, please notify me at XXX@waldenu.edu. I will contact you again to set up the interview via your choice of Zoom, Skype, or telephone.

The interview will be completed within 30 to 60 minutes. The interview will be audio-recorded, if you consent to, and you will have the opportunity to review the summary of my interpretations of our interview for accuracy before the inclusion of the study. I appreciate your valuable time. Your confidentiality will be protected. If you are interested in being interviewed even for a few minutes, please contact me at XXX or via email with any questions.

Regards,

Edward Zamanian

XXX@waldenu.edu

Appendix C: Interview Protocol

Interview Protocol	
What you will do	**What you will say—script**
Introduce the interview and set the stage	Thank you so much for your time. I understand how busy you are and greatly appreciate your engagement. I want to ask your permission to record this interview and assure you it is completely confidential. This interview and data collected isfor an assignment called a doctoral study, which is a graduation requirement. I would like you to know that your participation in this education assignment is to try to find strategies dental center leaders use to improve productivity using onsite 3D printing. I will interview you and no less than 4 other managers to gather information. First, I would like to begin by letting you know that your participation is voluntary. If there is any question that I ask, that you do not feel comfortable with you do not have to answer it or if you want to stop the interview at any time feel free to do so. Also, as I told you before I am going to audiotape this interview and I am going to take notes as well, is that OK with you? When your interview is complete, I am going to email you a one or two page summary of my interpretations within one week. If I misrepresented you in any way and if there is any information that you would like to add or take away just let me know. To ensure confidentiality, I plan to protect your identity, the name of your organization, and all data collected. I have set aside one hour for the interview and extended up to 30 minutes, if necessary.
• Watch for non-verbal queues • Paraphrase as needed • Ask follow-up probing questions to get more in depth	**Interview Questions** 1. What strategies do you use to improve productivity with onsite 3D printing? 2. How has your organization implemented strategies to improve productivity using onsite 3D printing?

	3. How do you measure the effectiveness of your strategies using onsite 3D printing? 4. How did you achieve productivity improvements with strategies using onsite 3D printing? 5. How did you address the key challenges implementing your strategies to improve productivity using onsite 3D printing? 6. How did you overcome any barriers to implementing your strategies to improve productivity using onsite 3D printing? 7. What additional information would you like to share regarding strategies to improve productivity using onsite 3D printing which was not included in the interview?
Wrap up interview thanking participant	Again, I want to thank you for taking the time to allow me to interview you. This concludes the interview.
Schedule follow-up member checking interview	I want to reiterate that I will email you a copy of my notes so that you can review them to ensure that I did not misrepresent you in any way. Also, to see if there is anything that you would like to add you can do so at that time. What would be a good time for you to meet for a follow up member checking interview next week? Looking forward to more conversation.
Follow–up Member Checking Interview	
Introduce follow-up interview and set the stage	I want to take time out to thank you for your participation in this study and for sharing your insight and documents related to strategies to increase productivity using onsite dental 3D printing. Were you able to review my notes from the interview?
Share a copy of the succinct synthesis for each individual question Did I miss anything? Or what would you like to add?	I have recorded the following evidence from your interview session and have summarized my understanding as per my transcription and I wish to verify with you any gaps, missing sections, or hard to understand responses. Reviewing of the summary of the

	interview responses to ensure accuracy will take approximately 30-45 minutes
At the close of each interview, I will thank each participant for taking the time out to participate in the study and give them a $25 gift card of their choice.	1. Question and succinct synthesis of the interpretation—perhaps one paragraph or as needed 2. Question and succinct synthesis of the interpretation—perhaps one paragraph or as needed 3. Question and succinct synthesis of the interpretation—perhaps one paragraph or as needed 4. Question and succinct synthesis of the interpretation—perhaps one paragraph or as needed 5. Question and succinct synthesis of the interpretation—perhaps one paragraph or as needed 6. Question and succinct synthesis of the interpretation—perhaps one paragraph or as needed 7. Question and succinct synthesis of the interpretation—perhaps one paragraph or as needed