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Adoption of Additive Manufacturing in Dental Technology Companies in Sweden

Comparative case study

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Abstract

Adoption of Additive Manufacturing in Dental Technology Companies in Sweden

Vinith Raja Sathish

Additive Manufacturing (AM) is one of the most advanced processes of producing high quality parts. In dentistry, AM has a wide range of applications, some of the most common applications are dentures, crowns, clear and hard tooth aligner, and anatomical and training models. Irrespective of its advantages, AM technology have not been used to its fullest potential. Research shows that there is very little knowledge on the organizational characteristics, environmental characteristics, and the technological factors that affects the organizational adoption of AM technology. The aim of the research is to understand the characteristics affecting the adoption decision among adopters and non-adopters of AM technology in dental technology companies.

To answer the research question, qualitative research method is used in this study. The data was collected by conducting semi-structured interviews with both the adopters and non-adopters of AM technology within the dental technological companies. The data collected was compared between the adopters and non-adopters. The main findings show that the adopters have a positive experience on AM technology and there is willingness to adopt AM technology in both adopters and non-adopters. Regarding the environmental characteristics, the practice of dentists was a major characteristic that impacted AM adoption. The technological factors related to the AM technology were identified to be the main drivers of technology adoption and the cost of AM machining was identified to be the main barrier of AM technology. The final findings from this research were that the technological factors, environmental factors, and the organizational factors are crucial for the successful organizational adoption of the technology.

Keywords: Additive Manufacturing, dental technology companies, organizational characteristics, environmental characteristics, technological factors, barriers, drivers.

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Popular Scientific Summary

Technology has created a shift in the society. Technology seeks to improve the quality of life through innovations which makes the process faster, efficient, and easier. One such technology that changed the market was the rise of Additive Manufacturing (AM) technology. The focus of this research is on adoption of AM technology. This technology has grown widely in healthcare, especially in dentistry. AM is transforming the practice in healthcare; this is because complex anatomical parts can be manufactured. The AM technology has been used extensively for complex surgeries, practicing surgeries, and designing and manufacturing implants.

This study focuses on the adoption of AM technology in dental technology companies in Sweden. Dental technology companies are the firms that manufacture various dental applications to assist or provide the various dental parts to the dentists. The purpose of the research is to cover some of the limitations or aspects that have not been well explored in the field. This research aims to understand the characteristics and factors affecting the adoption decision among the dental technology companies who are using AM technology and those who are not using AM technology from a top management perspective. Interviews with the top managers who are also lab technicians were conducted to facilitate the research. The interviews consisted of respondents who are adopters and non-adopters of AM technology. A detailed comparative study of the two groups was conducted. The findings shows that there are several factors that hindered the adoption of AM technology in dental technology companies. The main barrier was found to be the cost of AM machining and main driver for technology adoption was found to be the technology itself. The ease of use and the benefits of AM technology were the main drivers. In the case of non-adopters of AM technology, they show a willingness to adopt to this technology in future if there is a solution for the existing challenges in the technology.

This study will help the future adopters of AM technology in dental companies. The new adopters can learn from the adopters of AM technology on the difficulty in adopting, the difficulty in transition from the previous technology, the feel and use of the technology and finally the benefits they gain from this technology. The results from this study can be useful for preparing firms for technology adoption.

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Table of Contents

List of Figures

List of Tables

List of Abbreviations

AM- Additive Manufacturing

CAM- Computer-Aided Manufacturing

CNC- Computer Numerically Controlled

PBF- Powder Based Fusion

DMLS- Direct Metal Laser Sintering

CAD- Computer Aided Design

STL- Standard Triangulation Language

SLA- Stereolithography

UV- Ultra Violet

RP- Rapid-Prototyping

USPTO-United States Patent and Trademark Office

SLS- Selective Laser Sintering

FDM- Fused Deposition Modelling

XCT- X-ray Computed Tomography

DFM- Design for Manufacturing

IP- Intellectual Property

CBCT- Cone Based Computed Tomography

TOE- Technological Organizational Environmental

TPB- Theory of Planned Behaviour

DOI- Diffusion of Innovation

UTAUT- Unified theory of acceptance and use of technology

1 Introduction

This section covers a brief introduction of Additive Manufacturing technology and its application in dental technology companies. It also includes the problems related to the adoption of AM in dental technology companies, the purpose, aim and the research questions.

1.1 Background

Additive Manufacturing (AM) is one of the most advanced processes of producing high quality parts. AM has been implemented in industries such as medical, aerospace, automotive and tooling design applications (Al-Makky & Mahmoud, 2016). In medical field, the ability of AM to manufacture complex internal mesh structures and the ability to convert medical imaging data into a solid object has turned medical teams to research on AM in implants (used in the reconstruction of bone damage) and prothesis applications (Al-Makky & Mahmoud, 2016). AM in dentistry have contributed to many applications, some of the applications include the manufacturing of dentures, prosthetic aids, and lastly maxillofacial implants. AM can also be used in creating life like implants to replace the damaged tissues; however, the 3D printing tissue engineering is still in its nascent stages of development (Bhargav, et al., 2017).

Most of the dental technology companies (technology companies that produce medical devices for the oral care to support dentists) have access to CAD/CAM procedures either in the form of production centres, the dental laboratories or in the dental practice (Beuer, et al., 2008). According to Irfan et al (2015), cost is a major factor that limited the use of CAD/CAM procedures. Due to financial constraints, the dentists in the developing and under-developed countries are reluctant in using CAD/CAM procedures (Irfan, et al., 2015). The most commonly used Computer-Aided Manufacturing (CAM) process is Computer Numerically Controlled (CNC) machining. In CNC machining, power-driven machinery tools such as lathes, milling machines and cutting drills are used. The desired geometry is acquired by mechanically cutting the materials (controlled by a computer program). The limitations of these subtractive methods are the wastage of raw materials and replacement of milling tools (due to heavy abrasion and wear) (Revilla-Leon & Ozcan, 2017). With the use of AM, the limitations of subtractive methods can be met. In AM, the base material which is in powder or liquid state is structured into a solid object. The most commonly used tool for AM in dentistry is Powder-Based Fusion (PBF) Technology and the commonly used alloys for dental applications are cobalt-chrome (Co-Cr) and titanium (Ti) alloys (Revilla-Leon & Ozcan, 2017).

AM in dentistry has a wide range of applications. Some of the dental applications require prerequisites from AM technologies for optimal outcomes (Revilla-Leon & Ozcan, 2017). AM has been used in producing partial and complete dentures. A denture is a replacement for tooth and the tissues connected to the tooth. Direct Metal Laser Sintering (DMLS) is the process used for creating metallic dentures (Bhargav, et al., 2017). AM is also used in producing crowns that are used to cover a damaged tooth. Another application of AM is the creation of Anatomical and training models. The jaw, teeth and other organ models are created to enable the surgeons to plan for the surgery, this could increase the accuracy and reduce any error during the surgery.

In case of damaged organ, the anatomical model can be used to understand the level of damage and evaluate the treatment options. AM is also used in dental tissue regeneration (generated using a combination of cells and materials) (Bhargav, et al., 2017). AM can also be used to replace the skeletal parts of the jaw or a portion of the jaw (Bhargav, et al., 2017). The AM technology is beneficial during complicated cases when different surgical guides can benefit the surgeon. AM solves various problems in dentistry such as customization, denture position and retention, and improving existing dental implants (Javaid & Haleem, 2019). Irrespective of the benefits of AM technology, there are some of the aspects of AM technology which are not well explored in previous research. This is explained further in problematization section.

The project is a part of 'Additive Manufacturing for the Life Sciences Competence Centre' (AM4Life). AM4Life is a newly funded VINNOVA (Sweden's Innovation Agency) Competence Centre. AM4Life started in March 2020 and is set to be completed by December 2024. The purpose of AM4Life is to develop, give access to and support a future supply of competence and technology in the field of Additive Manufacturing for the Life Sciences (VINNOVA, 2020).

1.2 Problematization

Irrespective of the advantages of AM, the adoption rate of AM in general is relatively low (Ukobitz, 2021). AM has not been used to its full potential (Ramola, et al., 2019). The factors of technology, safety, and cost raise several questions among experts. There is also a requirement for training and education to advance the utilization of AM (Kety S., 2021). The other hurdles of adoption of AM in healthcare are the regulatory challenges (Ahmad, et al., 2019). In present, there are many drawbacks to AM technology. AM can only be applied to small-scale customizable products. Although the organizational adoption of AM has increased scientific interest from 2015 onwards, the findings by Ukobitz (2021) shows that the AM technology is still in the early stage. The research by Ukobitz (2021) shows that there is a vast knowledge on the advantages and disadvantages of AM for the organization, but there is very limited knowledge on the firm's environment and contingency factors that affect the adoption decision. The existing results reflect more on the intent of adoption rather than the experience of adopters who have already implemented the AM technology (Ukobitz, 2021). From the results of the research by Ukobitz (2021), it can be seen that there is a need to understand the factors that affect the adoption decision and the experience of adopters of AM. Although, the review of Ukobitz (2021) describes the adoption of 3D printing in general but does not focus on dentistry or healthcare it can be noted that the results of the literature review of Ukobitz (2021) can be applied to the dentistry industry as well.

1.3 Aim and purpose

The purpose of this research is to cover some of the limitations or aspects that have not been well explored in this field. The intent of this research is to understand the firm's technological and contingency factors that affects the adoption decision characteristics and get an insight on the experience of adopters who have already implemented AM in their production methods. This will be done by comparing the characteristics of adopter and non-adopters of AM technology. The research will be focused on the **'Adoption of Additive Manufacturing in dental technology companies'**. This research will investigate the effect of AM in dental technology companies. Based on the review by Ukobitz, (2021) three aspects of further research can be identified, 'Maturity of industry data', 'Characteristics of adopters vs non-adopters' and 'Impact of contingency factors' (Ukobitz, 2021). The societal value this thesis aims to deliver is facilitation of decision-making for future adopters of AM technology and providing insights on preparing firms for technology adoption.

In maturity of industry data, the focus will be on the action of adoption rather than the intent. The adoption behaviour of dental technology companies who have already implemented AM in their production process will be investigated. In terms of characteristics, this thesis will yield in understanding the adoption characteristics and facilitation of decision-making for future adopters. The characteristics of adopters and non-adopters of AM technology in dental technology companies will be compared from an empirical perspective, the comparison should result in insights on preparing firms for technology adoption. One of the most crucial drivers for adoption is the organizational readiness (top management support and experience) as Ukobitz (2021) stated based on the findings from existing literatures. In terms of the third aspect, the impact of contingency factors, the organizational characteristics such as technology readiness and existence of skilled workforce will be investigated. Ukobitz (2021) illustrated that the firm origin, size, and age may be the most important organizational characteristics for adopting AM technology. Ukobitz (2021) also illustrated that there are questions such as whether the incumbent firms are more likely to adopt than the new entrants.

The aim of the research is to understand the characteristics affecting the adoption decision among adopters and non-adopters of AM technology in dental technology companies. Three characteristics are focused on this research, they are organizational, environmental, and technological characteristics on combining the three aspects of further research, the research question (RQ) is proposed:

> **"What are the organizational, environmental and technological characteristics of adopters and non-adopters of AM technology in dental technology companies in Sweden?"**

2 Literature Review

This section includes a detailed study about AM, applications of AM in dentistry, production methods in dental technology companies, organizational characteristics, drivers and barriers of AM and the adoption of AM by dentists.

2.1 Additive Manufacturing (AM)

AM is being vastly integrated in manufacturing and is developing rapidly. It has become a part of our day to day lives. The concept of AM is that the three-dimensional (3D) designs can be manufactured from a computer-aided design (CAD) software without needing any specific tools or dies. It can be used in the manufacturing of personalized items or prototypes. In AM technology, the design contribution can be performed from any location across the globe, this has broken barriers of the need for localized engineers. These designs can be manufactured and tested from any location with very less lead time (Bandyopadhyay & Bose, 2019).

Gebhardt (2011) defines AM as an automated and revolving process developed from the principle of layer-based technology (Gebhardt, 2011). The definition of AM according to ASTM F42 Technical committee is the *"process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methods"* (GUO & LEU, 2013).

In AM, the representation of the part as portrayed in a 3D Computer Aided Design (CAD) is the data set for manufacturing the product. The data set is usually obtained by designing in CAD or by scanning or imagining technologies (Gebhardt, 2011). The CAD drawing contains the information of each layer that is going to be printed. Wong & Hernandez (2012) mentioned that the CAD file is converted to a standard triangulation language (STL) file format (Wong & Hernandez, 2012). The STL file is then imported to a software, where it is pre-processed. The information about each section is then electronically sent to the AM system (Negi, et al., 2013). The machine recreates the model as in the CAD from base side to the top until the object is complete. The object is produced in an additive fashion, layer by layer (Molitch-Hou, 2018). The final stage is the post-process, the physical part is removed from the platform, the object is then further cleaned, and surface treatment is completed to improve the appearance and strength based on the need (Negi, et al., 2013).

2.2 Emergence and Growth of AM

The AM technology has seen constant developments and improvement since the emergence of the technology. Due to the abilities and advantages of AM, the global markets have been expanding drastically. Figure 1 shows the growth of AM technologies over the years. It can be seen that there is gain of around six billion dollars around the time span of eighteen years (Bandyopadhyay & Bose, 2019).

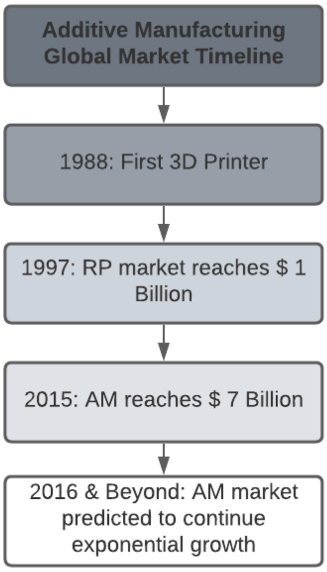

Figure 1 Growth of AM industry (Bandyopadhyay & Bose, 2019)

As adopted from Bandyopadhyay & Bose (2019), due to the continuous improvement seen in the industry, it is predicted that more than 10% of the products produced will be influenced by AM, however Bandyopadhyay & Bose (2019) does not predict or show the time line for attaining this growth. The technology and availability of AM continue to grow, AM technology will continue to be more integrated in the industry and our personal lives (Bandyopadhyay & Bose, 2019).

Stereolithography (SLA) was the first form of 3D printing, it was discovered by Charles "Chuck" Hull in 1980s. In SLA, the patterns are drawn using an ultra-violet (UV) light source to build a polymer layer. Once a layer is printed, the next layer of polymer is available on top of the existing layer. The process is completed once the product is printed completely based on the CAD design. The first patent of a Rapid-Prototyping (RP) system was approved by the United States Patent and Trademark Office (USPTO) in 1986, which was filed by Chuck Hull in 1984. Although this technology was patented in 1986, it took many years for the emergence of first solid state stereolithography system. After SLA, was the emergence of selective laser sintering (SLS). In SLS, the powdered material was spread on a build plate and a laser sintered the powder in certain areas of the plate. The first SLS machine was made in 1986. In the same timeline, another AM technology was being developed which is known to be fused deposition modelling (FDM). In FDM, the thermoplastic is heated to a semi-liquid state and deposited on a substrate and the product/part is developed layer by layer. This technology was patented in 1992. Since the early 90s, 3D printing has sparked an interest across the Globe and rapid improvements on the technology have been seen Worldwide (Bandyopadhyay & Bose, 2019).

During this period, it was still a hurdle to use RP technology to manufacture parts made of metals and ceramics. The first DMLS was prototyped in 1994 and was later launched in 1995. The SLS and DMLS has significantly advanced over the years and have become one of the most popular AM manufacturing processes. In the late 90s, another popular AM technology was developed which was the Electron Beam Melting (EBM). The process of EBM is that the electron beam is shot on the powder bed in selected areas, layers of powder are formed on top of each other until the desired part is complete. Using EBM technology, a hip implant was manufactured by an orthopaedic implant company in 2007. Ever since, EBM was used widely in the production of implants (Bandyopadhyay & Bose, 2019).

2.3 AM in healthcare

AM is transforming the practice of healthcare (Wong & Hernandez, 2012). AM technologies have a great potential in the field of healthcare. With the combination of AM and technologies such as CT or MRI scans, complex anatomical parts can be manufactured. The models built with AM technology provides accurate visualization of a specific anatomy. This helps the surgeons and practitioners to try out different surgical procedures realistically. It has been used vastly in the manufacturing of anatomical implants and tailor-made biomedical devices. With SLS process, dental implants and bone scaffolds can be manufactured. The process of FDM can be used in the manufacturing of fabrication of bone models and surgical guides (Negi, et al., 2013). One of the main advantages of AM is that it supports low volume production without the need of any additional tools, which makes it the most reliable approach used in the production of customized products such as medical implants. Since AM offers great freedom of design and allows the production of complex geometries; it can be implemented in the manufacturing of porous biological structures such as bones (Thompson, et al., 2017).

Initially, SLA was the AM process used in healthcare. The production of moulds and surgical guides were done using SLA. SLS, Selective Laser Melting (SLM), FDM and EBM are used in the production of end-use implants. In the recent years, material jetting technology is used in creating really complicated multi colour material models which can be used for visualization and surgical trainings (Thompson, et al., 2017). The scanning technology used commonly in healthcare to print the 3D models is X-ray Computed Tomography (XCT). The combined use of AM and XCT have been used prominently in the production of patient specific guides, this helps to ensure the correct placement of surgical screws and provides information to the surgeons on the correct drill hole angle and placement. Surgical guides are generally used for internal tissue surgeries, the main requirement is high precision and accuracy in volumetric scanning which can be achieved by AM and XCT technology (Thompson, et al., 2017).

Another major application of AM technology in healthcare is the production of implants (stand-alone and scaffolds). The clinical usage of implants producing by AM are becoming very common, mainly in the maxillofacial and orthopaedic applications. However, number of issues have raised preventing further adoption, for instance in the case of polymeric implants, the problems with material certification have prevented commercialisation (Thompson, et al., 2017). In a journal of Cranio-Maxillo-Facial surgery, Jardini et al. (2014) presents a case which involves the successful implementation of AM in Cranial reconstruction. Jardini et al. (2014) further compares the complexity that would arise in the conventional cranioplasty. The conventional cranioplasty techniques are dependent on the skills and experience of the surgeon. With the use of AM technology, a physical model with the same geometric characteristics can be obtained which reduces the probability of movement, displacement, or extrusion. The AM medical models can be used for complex surgeries, practicing surgeries (surgery simulation), design and manufacturing of implants (Jardini, et al., 2014).

The use of AM technology has been vastly implemented in the production of tissue scaffolds for implantation. However, the tissue scaffolds produced through AM have failed after a short duration of time, further research is being performed in the area of personalised regenerative healthcare (Thompson, et al., 2017). A review by Shirazi et al. (2015) points out the challenges that can be seen in tissue engineering. The SLS and inkjet 3D printing settings, the choice of biomaterials, and the clinical usage of AM processed parts were some of the biggest challenges (Shirazi, et al., 2015). Thompson et al. summarizes in the review that the primary barrier to adoption of AM in healthcare is the high cost of model production for a relatively small number of complex cases and another factor is the professional awareness (Thompson, et al., 2017) According to Negi, et al. (2013), irrespective of the wide applications of AM in medical industry, it cannot be used for daily practices due to the constraints of cost, type, and use of suitable materials. More research needs to be conducted in this field to lower the cost and development of suitable materials (Negi, et al., 2013).

2.4 AM in Dentistry

AM combined with XCT technology has found to have lots of applications in Dentistry (Thompson, et al., 2017). Collaboration among clinicians and laboratories can be enabled with the help of AM technologies to provide a solution for highly customized dental models (Javaid & Haleem, 2019). AM in dentistry is commonly used in the manufacture of crowns, implants, and bridges. The replacement of teeth, crown, braces, dentures, veneers, and aligners can be manufactured using AM technology (Javaid & Haleem, 2019). According to Javaid & Haleem, the significant benefits of adopting AM in dentistry are faster service, cost-effectiveness, accurate measurement of size of teeth, easily fabricate customised implants, reduce fabrication time, considerable reduction in inventory, rapid production of customized designs, and accurate sizing for implants (Javaid & Haleem, 2019). With AM technology, dentists have the advantage of using variety of materials (such as ceramics and metal alloys) for prosthodontics (Javaid & Haleem, 2019).

In a review article by Bhargav et al. (2017), the authors have illustrated elaborately on the different applications of AM in dentistry. Some of the most common applications of AM in dentistry are dentures, crowns, clear and hard tooth aligners, and anatomical and training models (Bhargav, et al., 2017). Some of the applications are explained in detail below starting with dentures.

2.4.1 Dentures

A denture is a replacement for teeth and the tissues that are associated with it. Dentures are removable and can be cleaned. Complete dentures are required to the patients who have lost their entire teeth and partial denture is when one tooth or a few teeth needs to be replaced (Bhargav, et al., 2017). The AM technology used in creating metallic dentures is DMLS. The commonly used alloy for dentures comprises of chromium, cobalt, and molybdenum. In some cases, to manufacture artificial teeth and temporary dentures, plastic is used. For producing plastic dentures, FDM technology is used. The plastic wires are melted and deposited in the shape of the denture. (Bhargav, et al., 2017). Goodacre & Goodacre (2022) conducted a narrative review to evaluate and compare the benefits and limitations of AM for complete denture fabrication. The results from the study showed that AM technology showed relative advantages of reduced cost of most printers when compared to the milling machines, less material waste when compared to the subtractive methods, simultaneous production of multiple dentures and achieving complex designs which cannot be achieved by milling machines. However, Goodacre & Goodacre (2022) pointed out that the factors of flexural strength, fracture toughness, colour stability and denture base application are better in the case of milled denture materials. The authors also pointed out that there is need for more research with this promising denture fabrication technique using AM technology to improve the flexural strength, fracture toughness, and colour stability as these factors are proven to be reduced when compared to the milling methods (Goodacre & Goodacre, 2022).

2.4.2 Crowns

Crowns are structures that can be used to cover a damaged tooth. The materials that are used in the manufacturing of crowns are usually inert materials such as gold, silver, or ceramics (Bhargav, et al., 2017). Methani et al. (2019), stated five different additive manufacturing technologies that can be used for the fabrication of all ceramic crowns, they are SLA, material extrusion, powder-based fusion, direct inkjet printing, and binder jetting (Methani, et al., 2019). Javaid & Haleem stated that the leading technologies in producing high quality crowns are SLA and DMLS (Javaid & Haleem, 2019). According to Methani et al. (2019), the digital dentistry has led to the adoption of AM technology for the fabrication of both resin and metal prothesis. However, the fabrication of ceramic crowns using AM are yet to witness the commercialization, it is still in nascent stages. The reason for this is because of the high number of variables associated with AM of dental ceramics such as type, manufacturer, processing techniques and other parameters. Methani et al. (2019) further states that the existence of literature related to AM of dental ceramic crowns is insufficient and dispersed. This resulted in difficulty in standardizing the outcome of the different literatures. However, the authors stated that the current studies show a great potential for fabricating ceramic crowns through AM technology (Methani, et al., 2019).

2.4.3 Clear and Hard Tooth Aligner

Clear and hard tooth aligners are usually used in the initial phase of dental treatments for dental problems like temporary mandibular disorders (TMD). The traditional way of treating TMD is by using hard steel-wire orthodontic brace. Teeth aligners are also known as occlusal splints (Pugalendhi, et al., 2019). The traditional method of creating a tooth aligner involves the initial stage of taking an impression of the teeth. On the impression in the plaster model, the corrections are made manually. With the use of the corrected plaster model, the fabrication of the aligner for the use of the patient is completed. This method consumes a lot of time, wastage of plastic material and requirement of skilled technicians (Pugalendhi, et al., 2019). The disadvantages of the traditional manufacturing method can be overcome in the case of clear and hard tooth aligner when incorporating AM to the production process, the integration of AM along with CAD produces a cheaper, faster, and economic product (Pugalendhi, et al., 2019). Pugalendhi, et al. (2019) conducted a pilot study to fabricate the tooth aligners with high precision, lower cost and increased comfort to the patients. The authors study shows that by incorporating AM technology to fabricate the tooth aligners resulted in decrease of total cost and total printing time as number of aligners fabricated in a single print increased. Pugalendhi, et al. (2019) further states that there was an increase in accuracy and reduced lab work on using AM techniques. The authors further conclude that in future, deployment of AM for dental aligners will be a potential approach and there is also a potential of further studies on the performance of the aligners with large number of patients (Pugalendhi, et al., 2019).

2.4.4 Anatomical and Training models

When AM was implemented in healthcare, it was used in the production of anatomically accurate objects which could be used for trainings, preparation, and planning for surgeries. This enabled to reduce the percentage of errors in surgeries. For instance, to understand the extent of damage on an organ and to evaluate the treatment options, AM is best suitable as it can print the exact visualization of the damaged organ (Bhargav, et al., 2017). According to Salmi (2020), the medical models are based on patient anatomy which can be used for trainings, pre- and post-operative trainings and explaining to the patient. These models are also sometimes used in the operation theatre (Salmi, 2021). According to Lichtenberger et al. (2018), the primary objective of AM in medical simulation and training is cost. The authors specify that with the increased availability of 3D printers in medical facilities and universities there is a promising future with cost effective methods in medical education and training (Lichtenberger, et al., 2018). Meglioli et al. (2020) in their review, discussed specifically on the application of 3D printed bone models in oral surgery, the authors stated that the surgical treatment times were reduced by 20% and failure rate was decreased when 3D printed oral models were used in planning and simulating surgical interventions. Like Lichtenberger et al. (2018), Meglioli et al. (2020) also points out that there is additional cost when producing 3D models. The training models for oral applications were expected to reproduce relevant haptic feedback (simulation of the sense of touch to communicate with the user) (engineeringproductdesign, 2017), and inexpensive investment with high level of accuracy (Meglioli, et al., 2020).

2.5 Characteristics of adoption of AM technology

Ukobitz (2021) classifies the characteristics as organizational, environmental characteristics and technological characteristics. The characteristics related to the organization are the internal characteristics such as firm size, financial and human resources, internal structure, and future vision (Ukobitz, 2021). Whereas the environmental characteristics are the external characteristics such as industry dynamics, competitors, trading parties and authorities (Ukobitz, 2021). The characteristics on focus in this research deals with the organization characteristics, the environmental characteristics, and the technological characteristics.

2.5.1 Organizational characteristics of adoption of AM technology

From the results of Ukobitz (2021), it can be seen the one of the main attributes for organizational adoption is the organizational readiness. Organizational readiness is stated as the firm's willingness to adopt to AM technology and experience with similar technology (Ukobitz, 2021). The Table 1 comprises of the organizational characteristics and its source.

Table 1 Organizational characteristics

S.NO	ORGANIZATIONAL CHARACTERISTICS	SOURCE
1	Willingness to adopt	(Ukobitz, 2021)
2	Top management experience	(Ukobitz, 2021) (Candi & Beltagui, 2018) (Chatzoglou & Michailidou, 2019) (Chau & Hu, 2001)
3	Perceived ease of use	(Moore & Benbasat, 1991)
4	Origin, size, age, location	(Ukobitz, 2021) (Mellor, et al., 2013) (Kianian, et al., 2016)
5	Structure and alignment	(Ukobitz, 2021)
6	Skilled workforce	(Ukobitz, 2021) (Choudhary, et al., 2021)

According to Ukobitz (2021), one of the utmost importance for successful organization adoption of AM technology is the experience of the top management with AM technology (Ukobitz, 2021) . Candi & Beltagui (2018), mentioned that the managers in the field of product development are either suspicious or enthusiastic about AM technology (Candi & Beltagui, 2018). Chatzoglou & Michailidou (2019) illustrated that the experience of managers is related to the 'attitude' (a person's positive or negative evaluation of performing a type of behaviour - (Chau & Hu, 2001)) and 'perceived ease of use' (Chatzoglou & Michailidou, 2019). From the results of Chatzoglou & Michailidou (2019), it can be found out that when an individual (manager) finds out the positive consequences from using AM technology, then the individual will have a greater intention to adopt AM technology (Chatzoglou & Michailidou, 2019). In the case of 'perceived ease of use' according to Moore & Benbasat (1991), if the individuals can learn easily on using the technology, then the individual can confidently use the technology effectively (Moore & Benbasat, 1991).

Ukobitz (2021) determined that origin, size, and age may be the most important factors for technology adoption (Ukobitz, 2021). According to Mellor et al. (2013), size of an organization is one of the crucial factors for understanding the process of new implementation of technology. Kianian et al. (2016), specified that small and medium-sized enterprises (SMEs) show to be the main driver main driver of AM technology in Swedish industry. Medium enterprises are industries with less than 250 employees and small enterprises are industries with less than 50 employees. According to Kianian et al. (2016), 99% of enterprises are SMEs. The results from Kianian et al. (2016) show that SMEs are dominant AM users showing 78% AM implementation beyond rapid prototyping in Sweden (Kianian, et al., 2016). The next important factor is the structure and alignment of the organization (Ukobitz, 2021). Mellor et al. (2013) states that structure of an organization is a key factor for adopting manufacturing technology. The authors analysed that the organizations face high difficulties when they adopt before first restructuring the organization. They further suggested that for successful adoption of AM technology the organization should change their work practice, structure, jobs and tasks (Mellor, et al., 2013). With respect to organizational perspective, Ukobitz (2021) mentioned that second most characteristic impacting AM adoption is the availability of existing workforce and the necessary reskilling of existing workforce (Ukobitz, 2021). According to Choudhary et al., (2021), there is a lack of skilled labourers and education, a training is required in order to achieve the full benefit of the AM technology. Further, the designers should be trained to decode data from CT scans. Additionally, the authors added that the workers also show resistance to adopt to the AM technology, the reasons include familiarization of the previous technology and fear of losing job as AM requires fewer workers (Choudhary, et al., 2021). Mellor et al. (2013) adds that when incorporating AM technology to the manufacturing process, the designers and manufacturers need to rethink the Design for Manufacturing (DFM) (Mellor, et al., 2013).

On compiling the results of organizational characteristics of AM technology, there is relatively less research on organizational characteristics of AM adoption. However, from the research it can be acquired that the organizational characteristics are the top-management experience, skilled human resources, structure and alignment of the organization, company size, age, and origin (Ukobitz, 2021).

2.5.2 Environmental characteristics of adoption of AM technology

The environmental characteristics are the external characteristics that affect the adoption of AM technology. The environmental characteristics stated in the previous research have been compiled in the table 2 below

Table 2 Environmental characteristics

S.NO	ENVIRONMENTAL CHARACTERISTICS	SOURCE
1	IP rights issues	(Gao, et al., 2015) (Despeisse & Minshall, 2017) (Stentoft, et al., 2021) (Dwivedi, et al., 2016)
2	Competitive pressure	(Jeyaraj, et al., 2006) (Yeh & Chen, 2018) (Wang, et al., 2010) (Zhu, et al., 2006)
3	Practice of dentists	(Christopoulou, et al., 2022) (Ciulla, 2020)
4	Governmental support	(Choudhary, et al., 2021) (Stentoft, et al., 2021) (Dwivedi, et al., 2016)

One of the environmental characteristics of adoption of AM technology is Intellectual Property (IP) rights issues. There are challenges in the social regulations and current legal landscape that protect the inventors from copyright infringement after the emergence of 3D printing marketplaces and open-source projects. There are measures taken by the researchers to protect the 3D models by encrypting into spectrum domain (Gao, et al., 2015). According to Despeisse & Minshall (2017), the current IP, legal systems, and security are not suitable for digital networks. Furthermore, they specified that the concerns of cyber security also hinder the adoption of AM technology (Despeisse & Minshall, 2017). According to Stentoft et al. (2020), illegally acquired digital models that can be used to produce products are easy to acquire and there is also a possibility of theft of digital models (Stentoft, et al., 2021). Further, the digital files can be shared easily and resold by unauthorized sellers. Due to the existence of unauthorized vendors, there will be a loss in revenue as well loss in reputation as the customers might be using sub-standard parts (Dwivedi, et al., 2016).

The next environmental factor is market competitiveness. Jeyaraj et al. (2006) stated that one of the positive implications of technology adoption is competition pressure (Jeyaraj, et al., 2006). According to Yeh & Chen (2018), some of the firms are forced to adopt to AM technology due to competitive pressure to improve the supply chain, inventory, and operational efficiency (Yeh & Chen, 2018). As market competition increases, firms tend to achieve competitive advantage through innovation and thus adopt AM technology (Wang, et al., 2010). Zhu et al. (2006) states that competition drives the firm to initiate and adopt innovations to maintain a competitive edge, however the authors state that the firms in highly competitive environments leap rapidly from one technology to another due to competitive pressures, by doing so, the firms retard the routinization of existing technology (Zhu, et al., 2006)

The next environmental characteristic that should be discussed is practice of dentists. The new inventions such as the intraoral scanning, cone beam computed tomography (CBCT) and 3D printing have introduced a digital era in dentistry (Christopoulou, et al., 2022). The intraoral scanner offers a lot of benefits such as reduced patient discomfort, time efficiency, simplification of clinical procedures, and storing highly accurate information (Christopoulou, et al., 2022). Despite of these benefits there are drawbacks of using intraoral scanners such as the cost, complicated software, and hardware (Christopoulou, et al., 2022). According to Christopoulou, et al., (2022), the older clinicians with lesser experience to digital technology face difficulty with the device and software. However, the adoption of AM technology relates to the adoption of intra-oral scanners as scanning is the first phase of the digital workflow (Ciulla, 2020). From the results of Ciulla (2020), it can be found that the main reasons stated by the dentists were the high initial investment with less number of practices performed daily (Ciulla, 2020).

Another factor stated by Choudhary, et al., (2021) is lack of governmental support. Government support is required to assess the safety and health hazards on implementing AM. This is essential when transferring from old technology to AM (Choudhary, et al., 2021). Furthermore, there is a need for initiatives from Government to protect IP rights issues, workforce development, health, and safety issues (Stentoft, et al., 2021). Dwivedi, et al., (2016) states that the Government must coordinate to generate uniform standard setting and is required to study the risk of IP rights infringements (Dwivedi, et al., 2016)

2.5.3 Technological characteristics for the adoption of AM technology

The characteristics related to the technology context are compiled from the research papers and listed below in Table 3

Table 3 Technology characteristics

S.NO		SOURCES
1	Cost	(Ukobitz, 2021) (Schniederjans & Yalcin, 2018) (Ajzen, 1991) (Hussain, 2021) (Dwivedi, et al., 2016) (Stentoft, et al., 2021) (Shukla, et al., 2018)
2	Time to market	(Ukobitz, 2021) (Choudhary, et al., 2021) (Gao, et al., 2015) (Dwivedi, et al., 2016)
3	Technology maturity	(Ukobitz, 2021) (Gao, et al., 2015) (Choudhary, et al., 2021) (Thompson, et al., 2017)
4	Supply chains	(Ukobitz, 2021) (Marak, et al., 2019) (Gao, et al., 2015) (Dwivedi, et al., 2016)

Table 3 (Continued)

5	Ease of use and customization	(Marak, et al., 2019) (Cohen, 2014) (Mohsen, 2017) (Mani, et al., 2014)
6	Reduction of environmental impact	(Ukobitz, 2021) (Schniederjans & Yalcin, 2018) (Mason, 2010) (Gao, et al., 2015)
7	Material maturity	(Gao, et al., 2015) (Mellor, et al., 2013) (Schniederjans & Yalcin, 2018)
8	Complexity of software	(Garza, 2016) (Gao, et al., 2015)

Starting with the first characteristics, investment costs are the most dominant barriers of AM adoption (Ukobitz, 2021). The important aspects of investment costs include the high cost of technology acquisition, cost of the materials and the cost of unexpected maintenance (Ukobitz, 2021). Along with the investment costs are the costs of the computer systems, software and the labour costs hired to use the AM machine. The raw materials are very expensive, especially when exotic materials such as titanium can cost of thousands of USD per ounce (Schniederjans & Yalcin, 2018). With the research and development in the AM field, the cost of machines and materials have reduced over the years, however Dwivedi et al. (2016) state that the costs of high-grade materials and machines are still high (Dwivedi, et al., 2016) . Furthermore, Stentoft et al. (2020) illustrates that it is very hard to create adequately accurate cost models and there is no clear understanding on the costs associated with the technology, especially in the case of metal-based AM (Stentoft, et al., 2021). Shukla et al. (2018) states that the companies need to invest in several different types of printers to produce meaningful variety of products (Shukla, et al., 2018). Hussain (2021) mentioned that the barrier of using AM machining in dental applications when compared to the conventional dental labs is the initial cost of AM systems is higher than the traditional dental equipment (Hussain, 2021).

The next characteristic is the time to the market, with the help of AM technology, the time to the market can be accelerated, this is because with AM it is possible to do rapid prototyping and rapid manufacturing which indeed reduce the lead-times and ramp-up times (Ukobitz, 2021). AM technologies are suitable for fabricating products which are customizable, low volume production and with increased geometric complication (Gao, et al., 2015). 3D printing is considered to be faster than any available manufacturing methods hence providing customers a higher service level (Schniederjans & Yalcin, 2018). However, that many authors credited in favour of AM technology regarding the speed on AM machines, Dwivedi et al. (2016) stated that the production rate and throughput rate is lower when compared to the conventional manufacturing (Dwivedi, et al., 2016). Thompson et al. (2017) also added that when comparing AM to traditional machining or injection moulding, the number of products produced in AM are relatively less, they possess longer production times and poorer mechanical properties (Thompson, et al., 2017).

The factor to be discussed after the time to the market are the drivers and barriers related to supply chains. As there are shorter lead times, there is an opportunity to simplify the supply chain. By simplifying the supply chains there is a possibility to lower the inventory and production steps such as tooling and moulding function. This thereby is a beneficial driver for adoption of AM technology (Ukobitz, 2021). Marak et al. (2019) specified that AM technology can improve and shorten the value chain (Marak, et al., 2019). The other benefits include lower supplier independence and less production errors (Ukobitz, 2021). However, there are some barriers with the aspect to supply chain as well. Mellor et al. (2014) states that vendor support is crucial for successful AM implementation. According to the research of Dwivedi et al. (2016), there is a less availability of AM machine suppliers and AM material suppliers which gives the suppliers a high negotiation power. Additionally, there is a lack of trust on the suppliers, this is due to the poor service after sales, low knowledge on the technology and no communication between suppliers and the firm. Due to these constraints, it affects the firm's decision process on adopting AM technology as the firm might have to depend on a specific supplier for future supply (Dwivedi, et al., 2016).

The next important factor is technology maturity, which is based on two aspects, one is the lack of standardization and the second is output quality (Ukobitz, 2021). The variety of materials, machines, and processes available in AM have made it challenging to have a uniform standard for AM technology. This made it difficult for the manufactures to supply custom consumables and spares (Gao, et al., 2015). Choudhary, et al., (2021) further stated that there is a need to meet specific standards or high specifications at every step of the manufacturing process. However Thompson, et al., (2017), stated that AM specific standards will be more relevent and complete in the future and new AM specific standards will be implemented. Coming to the output quality, in AM technology, a good surface finish is obtained by having a high layer resolution or smaller layer thickness. However, this increases the total build time as more layers are required to obtain the required geometry (Gao, et al., 2015). Additionally, Choudhary, et al., (2021), stated that there is a lack of techniques for surface finishing and coating of AM produced parts due to the complex geometry.

The next factor is the ease of use of AM technology and mass customization. According to Marak et al. (2019), the AM process offers speed, flexibility in designing and in modifying products and are easy to use (Marak, et al., 2019). Cohen (2014) stated that with AM technology mass customization could be acquired and this increases the possibility to change the way the companies manufacture their products to market and respectively respond to the needs of the customer. AM technology allows the mass customization of up to 200 products a time (Cohen, 2014). According to Mohsen (2017), with the use of AM technology quick production of parts which are exactly customized can be achieved on site preventing the need for redesign (Mohsen, 2017). Mani et al. (2014) states that with the ability of AM technology to build parts directly from digital impressions has made it an easier process for highly customized parts. Furthermore, AM technology accelerates mass production by making tools and dies used in large volume manufacturing (Mani, et al., 2014).

The next important driver of AM technology is the reduction of environmental impact (Ukobitz, 2021). According to Schniederjans & Yalcin (2018), the ability of AM to enable remanufacturing reduces the impact of tool and die manufacturing results. The authors also specify that there is less energy consumption in AM as the process is more autonomous with shorter production time. Further, AM also reduces the resources as it eliminates the process of melting excess scrap, the reduction of waste also reduces the cost of raw materials (Schniederjans & Yalcin, 2018). Marak et al. (2019) added that with AM technology there is an ability to reuse the material and hence reducing material waste (Marak, et al., 2019). AM is implemented in scenarios where low material waste is required and there is demand for customized geometry (Gao, et al., 2015).

The next major factor is material maturity. The selection of materials that can be used in AM are limited. Most of the AM technologies have the capability of processing only a single material at a time. Although there is research on multi-material AM systems, there exists an uncertainty of behaviour at the material interfaces (Gao, et al., 2015). Mellor, et al., (2013) and Schniederjans & Yalcin (2018) also specified the availability of materials as a major barrier for adoption of AM technology (Mellor, et al., 2013), (Schniederjans & Yalcin, 2018). From the findings of Dwivedi et al. (2016) it can be found that AM technology limits the use of materials by the designers as there is a low variety of available materials. The authors further state that acquiring the desired strength and finish from the list of materials available for AM technology is a critical barrier to technology adoption (Dwivedi, et al., 2016). Berman (2012) illustrated that the material choices, colors and surface finishes suitable for AM technology are limited than with typical mass-production processes (Berman, 2012). Niklas et al. (2018) conducted a quantitative analysis to analyse the commercially and readily available materials for AM technology, the results showed that the printable materials could be increased if a substitution of original material was taken into account, furthermore the number of available printable materials are demonstrated in research environments but is not yet available for industry usage. Niklas et al. (2018) concludes that there will be a large share of materials that can be printed in future (Kretzschmar, et al., 2018).

The last factor related to technology is software complexity. Garza (2016) pointed out that using CAD software was the greatest hurdle when using 3D printer. For a novice user of CAD software, it takes the longest to model the product (Garza, 2016). Gao et al. (2015) specified that the existing software packages are complicated and analysing multi-material geometry is complex (Gao, et al., 2015). The possible uses of AM technologies are limited because of the capability of software and digital scanners, for instance, to fabricate a zirconia framework, the AM labs still require conventional lab processing for manual veneering with conventional porcelain by dental technicians (Hussain, 2021).

2.6 Technology-organizational-environment framework

The TOE framework can be used to understand the adoption of AM technology from organizational perspective (Tsai & Yeh, 2019). Tornatzky et al. (1990) has developed the TOE frameworks to examine complex decision process (Tornatzky, et al., 1990). The TOE framework is supported by three crucial factors that influence AM technology. As the name suggests, the factors that play a role in technology adoption in this framework are technological factors, environmental factors, and finally the organizational factors (Ukobitz, 2021). Figure 2 represents the layout of TOE framework (Tsetse, 2014). According to Ukobitz (2021), the technological factors deal with relative advantage of the organization and the compatibility with existing structures (Ukobitz, 2021). The organizational factors are more of the internal characteristics of the firm such as the firm size, resources, and structure of the organization (Ukobitz, 2021). Finally, the environmental characteristics deal with external drivers such as competitors, trading partners and authorities (Ukobitz, 2021).

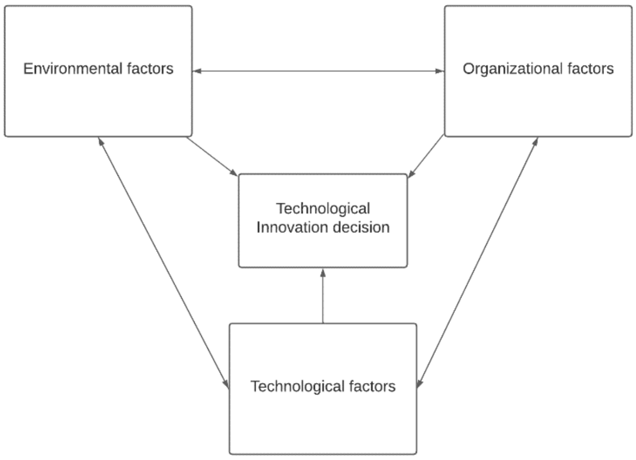

Figure 2 TOE Framework (Tsetse, 2014)

Ukobitz (2021) stated that the TOE framework deals with the technology adoption rather than the intent of adoption. According to Yeh & Chen (2018), the TOE framework was most frequently employed in the study of radical innovation and its initial applications on the literatures of adoption of AM technology (Yeh & Chen, 2018). Unlike the other adoption models as Theory of Planned Behaviour (TPB), Diffusion of Innovation (DOI) or Unified theory of Acceptance and Use of Technology (UTAUT), the TOE model does not exhibit the decision-maker characteristics, however it throws light on the management's experience, vision, and support (Ukobitz, 2021). Hsu et al. (2006) stated that TOE is a more appropriate model than DOI to analyse the intrafirm adoption (Hsu, et al., 2006). For this research TOE framework will be the most appropriate framework as it studies the technological, environmental, and organizational factors which are directly related to the RQs. Moreover, as stated before with TOE framework the technology adoption from organizational perspective can be understood. The TOE framework will be implemented in this research based on the findings from adopters and the non-adopters. The result of the TOE framework from the two groups can result in a detailed discussion and the possibility to clearly describe the factors of each adopter and non-adopter of AM technology.

This literature review will be followed on by the methodology section. The methodology sections describe the methods used in this research to obtain the desired results.

3 Methodology

This section provides a detailed information of the selection of methodologies. The research design, sampling, research participant, data collection methods and data analysis used in this research and its link to the research question will be explained here.

3.1 Research Strategy

As per Bell, et al. (2019) a qualitative study is used to evaluate research which is concerned more on the words rather than numbers. One of the highlights of qualitative study is that the connection between theory and research is open to more than one interepretation unlike the quantitative research methodology (Bell, et al., 2019). The outcome of a qualitative research study is a theory and not something that preceeds it. The collection of data and analysis of data results in the emergence of theory and categorization (Bell, et al., 2019). Lakshman et al., (2000) states that qualitative methods provides a great understanding regarding the knowledge, practices, life events of people and beliefs. The authors also specified the classical examples of qualitative methods which included the studies of behaviour and the study of clinical practices involved in healthcare (Lakshman, et al., 2000). Unlike qualitative approach, the quantitative involved in the collection of numerical and exhibts the relationship between theory and research (Bell, et al., 2019). According to Bell et al. (2019), the limitations of quantitiative methods is that is limits the connection between research and everyday life. LaPiere (1934) further stressed that quantitative methods can be used to illustrate the motivation to work but fails to stress on the respondents actual behaviour (LaPiere, 1934). Furthermore, Lakshman, et al. (2000) also stated that the healthcare practices involving the complex decisions of using new technologies cannot be evaluated by quantitative methods.

On looking back to the two research questions, the RQ1 involves the characteristics of adopter and non-adopters and the RQ2 involves with the adoption behaviour. As stated in Chapter-1, the aim of the research is to understand the adoption behaviour and characteristics of adopters and non-adopters of AM technology. Barrett & Twycross (2018) mentioned that qualitative research allows the researchers to explore how the decisions are made (Barrett & Twycross, 2018), decision making is an aspect of RQ1. From the statements of Bell, et al. (2019)., Barrett & Twycross, (2018)., and Lakshman, et al., (2000), the appropriate methodology for this research selected is qualitative research methods. According to Bell, et al. (2019) there are two central aspects of qualititative research, (1) Fullest participation condition in the mind of another human is obtained through face-to-face interaction and (2) To acquire social knowledge, it is required to participate in the mind of another human (Bell, et al., 2019). For this research, it is crucial to have one-on-one interaction with the research participant to answer the research questions, which makes qualitative research the suitable methodology to conduct this research. Additionally from the statements of LaPiere (1934) and Lakshman, et al. (2000), quantitive methods cannot be applied for this research as this research involves studying the adoption behvaiour and is also related to healthcare practices.

The relationship between theory and research can be split in three different terms, deductive study,inductive study and abductive study. Deduction entails a process in which the study starts with a theory and results in observations, whereas in induction, the findings and observations results in theory (Bell, et al., 2019). According to Bell, et al., (2019) the linkage of theory and data through inductive strategy is often associated with qualitative research (Bell, et al., 2019). Whereas, the abductive reasoning starts with the observation of phenomena and then seeks to develop explanations for them by working iteratively between theory and data (Bell, et al., 2019). In this research, the findings and observations made from the research should result in obtaining theory or contributing to existing theory which answers the research questions and corelates with the aim of the research. However, the existing research in this field can support the various aspects of research such as the factors and characteristics of AM adoption. The findings of previous research and the new findings of this research is essential to answer the research questions, therefore the finidings and the previous research were dealt iteratively, making abductive study the right approach for this research.

The research strategy will be followed by the research design and the data collection method or research method (Bell, et al., 2019). These are covered in the next sections.

3.2 Research Design

The definition of research design according to Bell, et al., (2019) is "A research design is a framework for the collection and analysis of data" (Bell, et al., 2019). In this research, the main objective of the study is to focus on AM in dental technology companies in both adopters and non-adopters of AM technology. On comparing to the research designs, a case study is an in-depth analysis of a single case, and they are often associated with qualitative methods (Bell, et al., 2019). Gerring (2007) defines case study as "the intensive study of a single case where the purpose of study is to shed light on larger class of cases" (Gerring, 2007).

The research in focus is an in-depth study and case study seems to be the ideal research design. A case can either be an intensive study of a single organization, a single location or a person (Bell, et al., 2019). In this research, multiple dental technology companies are going to be studied, which makes several cases. Since there is more than one case involved the research design for this research is 'Multiple-case study design' or 'comparative case study' (Bell, et al., 2019). According to Baxter & Jack (2009), a multiple case study enables the researcher to investigate two or more cases and evaluate the differences within and between the cases (Baxter & Jack, 2008). Bell, et al. (2019), stated that the multiple case studies are most commonly used for the purpose of comparing the cases that are included. This contributes in allowing the researcher to compare and contrast the findings or results from each of the case (Bell, et al., 2019). In this research, the findings from the all the cases identified will be compared and contrasted accordingly. However, the results from multiple case studies are proven to be robust and reliable, the disadvantage of multiple case studies are the time consumption and overall cost (Baxter & Jack, 2008).

3.3 Sample Selection

The sampling type is purposive sampling, purposive sampling is a type of non-probability sampling. The sampling is made from an existing collection of quantitative data from 217 dental technology companies in Sweden, who are both adopters and non-adopters of AM. This data was collected as part of another research project which consisted of the details of the firm such as the location, number of resources, start date and so on. All the firms were dental technology firms. The quantitative data consisted of 457 dental technology companies as its entire population, out of which there where 217 respondents. From the 217 dental technology companies, an informed selection of firms for the data collection was made. For this research, the target population considered were top managers in the dental technology companies, as Ukobitz (2021) stated that top management support and experience are one of the crucial drivers for adoption (Ukobitz, 2021). Sweden was selected for this research because it is considered as the second most innovative country after Switzerland according to the 2021 ranking of global innovation index (Larson, 2021). The selection of sampling was a strategic selection of both adopters and non-adopters of AM technology. The selection of research participants was made based on the below mentioned sampling criteria from the obtained data of 217 dental technology companies. The adopters of AM technology are the dental technology companies who have incorporated AM in their production process and non-adopters are the dental technology companies who have not incorporated AM in their production process. However, it is to be noted that most of the participants from the 217 dental technology companies had previously indicated that they were not interested to take part in research. Therefore, phone calls were made to every adopter (38 adopters) and non-adopter (33 non-adopters) of AM technology who belong to the top management position with experience as a dental technician and who have previously mentioned as available for interviews. All who agreed to participate were included in the research.

Criteria for selecting sample research participants (adopters):

1. A member from the top management such as CEO, co-founder and lab managers who currently work in the lab as well.
2. Experienced in AM in dental applications (dentures, crowns, orthodontic braces, bridges) and have enough knowledge about it.
3. Have collaborated with dentists and are aware of the requirements in dentistry applications.
4. Available for interviews.
5. Dental technology company within Sweden.

Criteria for selecting sample research participants (non-adopters):

1. A member from the top management such as CEO, co-founder and lab managers who currently work in the lab as well.
2. Experienced in production technologies within dental applications (dentures, crowns, orthodontic braces, bridges) and have enough knowledge about it.
3. Have collaborated with dentists and are aware of the requirements in dentistry applications.’

4. Available for interviews.
5. Dental technology company within Sweden.

According to Hennink & Kaiser (2022), a required sample size is needed in qualitative research to obtain saturation. The findings of Hennink & Kaiser (2022) show that saturation can be achieved by conducting 9 to 17 interviews (Hennink & Kaiser, 2022). With the basis on time constraints and to satisfy the minimum required sample size, around 9 to 12 interviews was planned. Two groups comprising of equal number of respondents was considered (adopters and non-adopters).

3.4 Data Collection

Barrett & Allison, (2018), stated that qualitative research requires data which are rich and holistic (Barrett & Twycross, 2018). In qualitative methods, there are a several data collection methods, the commonly used methods are observations and interviews (Gill, et al., 2008). According to Gill, et al. (2008), the most common data collection methods used in healthcare research are interviews and focus groups. The characteristics of many qualitative studies involve the collection of data through interviews with research participants, as it is possible to gather rich and detailed information regarding a particular research focus or area (Barrett & Twycross, 2018). The most common way of conducting interviews is through face-to-face interviews, however telephone interviews are increasing in popularity as it can overcome the barriers of geographical constraints (Barrett & Twycross, 2018). Open and unstructured interviews are generally used for research requiring a narrative enquiry, they are shaped by the conversation in real time (Barrett & Twycross, 2018). The disadvantage of unstructured interviews is that it is difficult for the researcher to maintain the focus of the interview and might ponder to other areas of discussion (Barrett & Twycross, 2018). Gill, et al. (2008), also mentions that unstructured interviews are time consuming and are usually difficult to manage as there are no predetermined interview questions to guide the interview (Gill, et al., 2008).

The most common approach used in qualitative research is semi-structured interviews (Barrett & Twycross, 2018). In semi-structured interviews, the questions structured in the interview guide are within the focus of the research. The respondents were flexible to share their perspective to support the discussion (Barrett & Twycross, 2018). They were comprised of several key questions that was within the research domain (Gill, et al., 2008). Gill, et al. (2008) states that the semi-structured interviews are most frequently used in healthcare research. To this end, the selected methodology for data collection is semi-structured interviews. Choosing a structured interview will not offer the flexibility of the research participant to discuss his views and on the other hand, an unstructured interview might de-align from the research. The data collection method was completed by conducting semi-structure interviews with nine research participants (4 adopters and 5 non-adopters). This process was involved by preparing an interview guide, conducting interviews, recording, and transcribing. The interviews were held through zoom based on the interviewee's preference. The interview guide led to the collection of data, which when analysed resulted in answering the research questions.

Table 4 shows the result of the data collection along with the details like position, gender, age of the firm, size of the firm and location of the 9 respondents. For easier purpose, better understanding and to also maintain the confidentiality and anonymity of the companies, the adopter companies will be labelled as R1A (Respondent 1 Adopter), R2A and so on and the non-adopters will be labelled as R1NA (Respondent 1 Non-Adopter), R2NA and so on.

Table 4 Compilation of research participants

S.NO	Company	Uses AM?	Position	Gender	County	Number of employees	Established
1	R1A	Yes	Lab manager/ Lab technician	Male	Stockholm	7	Since 2015
2	R2A	Yes	Owner/ lab technician	Male	Västmanland	1	Since 2020
3	R3A	Yes	Lab technician and owner	Female	Skåne	1	Since 2018
4	R4A	Yes	Owner/lab technician	Male	Skåne	4	Since 2019
5	R1NA	No	CEO/ lab technician	Male	Stockholm	6	Since 1985
6	R2NA	No	Lab technician and owner	Male	Stockholm	1	Since 1984
7	R3NA	No	Lab technician and owner	Male	Jönköping	4	Since 2015
8	R4NA	No	Co-founder / lab technician	Male	Jönköping	10	Since 2012
9	R5NA	No	Lan manager/ dental technician	Female	Västra Götaland	5	Since 1985

3.4.1 Interview guide

According to Gill, et al., (2008), when designing an interview guide or schedule, it is important to construct questions that will result in detailed information to address the aims and objectives of the research. In an interview guide, the good questions are suggested to be open ended, neutral, sensitive and understandable and the format is to start with the easy and general questions before heading to the difficult and sensitive topics (Gill, et al., 2008). According to Kallio, et al. (2016), there are five phases to formulate an interview guide, which involves (i) identifying the pre-requisites for using semi-structured interviews, (ii) retrieving and using previous knowledge, (iii) formulating the preliminary semi-structured interview guide, (iv) pilot testing the interview guide and, (v) presenting the complete semi-structured interview guide.

3.4.1.1 Phase (i): Identifying the pre-requisites for using semi-structured interviews

The aim of this phase is to evaluate the semi-structured interview as a suitable data collection model (Kallio, et al., 2016). This step was completed in the chapter 3.3, and it was concluded that semi-structured interviews is the suitable data collection method for this research.

3.4.1.2 Phase (ii): Retrieving and using previous knowledge

The next phase to formulate an interview guide is to gain a basic understanding of the research phenomena, for pre-interview preparations it is important to have a good knowledge about the research topic (Kallio, et al., 2016). The phase was completed in chapter 2, literature review. The results obtained from the literature review gained in the understanding of applications and barriers of AM technology and summary of theoretical frameworks related to technology adoption. The literature study concluded in resulting of formulation of barriers and the primary barrier of adoption of AM technology being high cost of model production with relatively small number of complex cases. The other main finding from previous literatures was that the top management considered that perceived usefulness and compatibility of AM technology were the main drivers for adopting AM technology (Schniederjans & Yalcin, 2018).

3.4.1.3 Phase (iii): Formulating the preliminary semi-structured interview guide

In this phase, the aim was to formulate the interview guide as a tool for data collection (interview) using the knowledge acquired from the previous phases (Kallio, et al., 2016). The interview guide should assist the conversation towards the research topic by listing out a series of questions (Kallio, et al., 2016). The quality and the questions framed in the interview guide directly impacts the analysis of the collected data (Kallio, et al., 2016). According to Bell, et al., (2019) some basic factors to be considered when preparing an interview guide are (i) creating an order on the topic areas, (ii) formulating questions to answer the RQs, (iii) use of relevent and comprehensive language, (iv) avoid leading questions, and (v) record facesheet with information of research participant (Bell, et al., 2019). As this research is a comparitive study, two sets of interview guides will be formulated. One set specific for the dental technology companies who have adopted AM technology and the other set specific to the non-adopters. This is shown in Appendix A and B. The table shows the layout of interview guide and how the questions will vary depending on the answers of the respondents.

3.4.1.4 Phase (iv): pilot testing the interview guide

The aim of this phase is to test the interview guide. By testing the interview guide, the interview questions can be reformulated (Kallio, et al., 2016). According to Kallio, et al., 2016, the pilot test of the interview guide can be done in three ways, internal testing, expert assessment and field-testing. For this research, the internal testing and expert assessment was conducted by the subject readers and supervisors guiding the research and depending on the effectiveness of the interview guide, the interview guide was altered. Field-testing was not conducted due to the constraints of time.

3.4.1.5 Phase (v): Presenting the complete semi-structured interview guide

The aim of the final phase was to produce a completed interview guide which is clear, logical, and is aligned with the research topic (Kallio, et al., 2016)

Appendix A and B shows the interview guide formulated by following all the phases as mentioned by Kallio, et al. (2016). Appendix A illustrates the interview guide for adopters of AM technology and Appendix B illustrates the interview guide for non-adopters of AM technology.

3.5 Data Analysis

In qualitative research, themes and findings are derived through careful analysis (Barrett & Twycross, 2018). Although the qualitative data obtained is rich, Miles (1979) states that it is difficult to analyse the data through its richness and hence termed it as "attractive nuisance" (Miles, 1979). Bell, et al. (2019), stated that when analysing qualitative data it often gets difficult in knowing where to start, this is because there are only a few well-established and widely accepted methods for analysing qualitative methods (Bell, et al., 2019). Out of the few established methods, the most frequently used methods are grounded theory and thematic analysis (Bell, et al., 2019).

The methodology used for data analysis is Thematic Analysis. Thematic analysis is the process of analysing classifications and presenting themes that relate to the data (Alhojailan, 2012). According to Bell, et al. (2019), a theme is a category identified by the analyst, which is related to the focus of the research, builds on codes and provides the researcher the basis of theoretical understanding (Bell, et al., 2019). Thematic analysis is suitable for this research as the results are drawn using interpretations. Participant's interpretations are important in deriving explanations for their behaviours, actions, and thoughts (Alhojailan, 2012). This is critical for the research as deriving the characteristics of adopters and non-adopters and understanding the adoption behaviour is a part of the research. Moreover, Thematic Analysis provides an understanding of the current practices of any individuals and can also be used in determining the relationship between concepts and comparing them with the data (Alhojailan, 2012). The data gathered from interviewing the participants will be thematically analysed to present the data effectively and bring out the reality of data collection (Alhojailan, 2012).

According to Ryan & Bernard (2003), there are some recommendations when looking for themes, which involves seeking repetitions, categories, metaphors and analogies, transitions, looking for similarities and differences, missing data, and theory related material (Ryan & Bernard, 2003).

3.5.1 Thematic Process

Alhojailan, (2012), stated that in thematic analysis process, the data is analysed without engaging pre-existing themes, each statement or idea by the participant contributes to understanding the concept. Alhojailan (2012), summarized the process of thematic analysis in three phases, data reduction, data display and data conclusion.

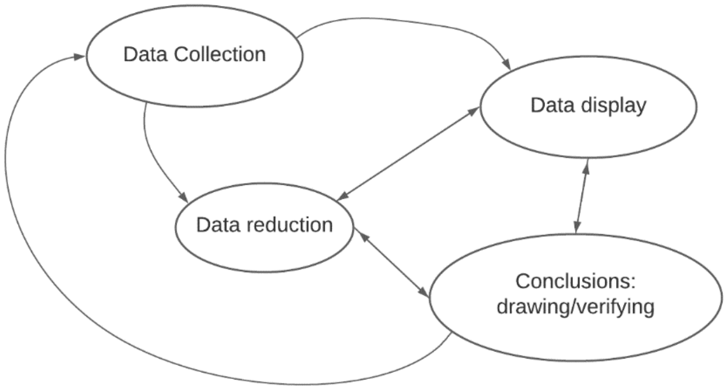

Figure 3 Data Analysis: Iterative model (Miles & Huberman, 1994)

The thematic analysis process is illustrated by using the components of Data Analysis: Interactive model as illustrated by Miles & Huberman (1994). Figure 7 represents the data analysis interactive model (Miles & Huberman, 1994).

The interactive model shows the three types of analysis and the data collection itself form an iterative cyclic process (Miles & Huberman, 1994). The data reduction should generate new ideas on what should go on to the data display. As the data display fills up, preliminary conslusions could be drawn (Miles & Huberman, 1994). Miles & Huberman (1994) states qualitative data analysis as a continuous iterative enterprise.[1]

3.5.1.1 Data Reduction

The data reduction phase involves three sub-phases. In the first phase of data reduction, the data collected is tabulated in a document prior to organizing the content of data. The data are then analyzed word-by-word using tables to identify the codes. Reading the data a few times before and after framing the codes could be beneficial for the researcher (Alhojailan, 2012). In the second phase of data reduction, the codes which are aligned to answer the research questions are highlighted for each participant, all the relevant data must be highlighted before getting to the third stage of data reduction (Alhojailan, 2012). The final phase of data reduction involves using the highlighted sentences to breakdown to smaller segments or themes. Thereby the codes are led to the formulation of themes and sub-themes. Once a set of themes are obtained, it is important to look for missing information by reading the full content again (Alhojailan, 2012). It is important to look into the theme's reliability and validity before heading to the next stage of thematic process (Alhojailan, 2012). In data analysis, it is essential to validate the themes in the early and late stages of analysis (Miles & Huberman, 1994).

3.5.1.2 Data Display

The second important phase of thematic analysis process is the data display (Miles & Huberman, 1994). The data reduction and data display complement one another. In data display, the data is organized by using variety of techniques such as figures, tables, narrative texts, quotations, charts and graphs (Alhojailan, 2012). The data display helps in exploring the similarities and differences between the data collected by representing the data in clusters for analysis (Alhojailan, 2012).

3.5.1.3 Data drawing and conclusion

The final phase is the data drawing and conclusion (Miles & Huberman, 1994). To conclude the data reduction and data display after displaying the data in several ways, the grouping information that can go together must be validated, identification of interrelations among factors and variables must be validated and finally building conceptual coherence and consistency (Alhojailan, 2012).

3.6 Data quality

Bell, et al., (2019) states that, to evaluate a qualitative study, two primary criteria for assessing a qualitative study can be considered, they are trustworthiness and authenticity. To assess the trustworthiness, four factors are to be evaluated as trustworthiness is made up of those four factors which are credibility, transferability, dependability, and confirmability (Bell, et al., 2019).

3.6.1 Trustworthiness

The first factor of trustworthiness is the credibility. According to Holloway & Wheeler (2002), credibility is defined as "the confidence that can be placed in the truth of the research findings" (Holloway & Wheeler, 2002). The credibility is established when the information drawn from the participant's original data is a correct interpretation of the participant's original views (Anney, 2014). To ensure credibility of the data peer debriefing was conducted, this was done by seeking support with subject reader, supervisors, and remarks from seminar presentations. The scholarly guidance from the academic staffs ensured the credibility of the research. The next factor is transferability, it is defined as "the degree to which the results of qualitative research can be transferred to other contexts or settings with other respondents" (Bitsch, 2005). To ensure the transferability, Bell, et al., (2019) suggested that by giving 'thick description', the transferability can be increased. The third factor of trustworthiness is the dependability. Bitsch (2005) defined dependability as "the stability of findings over time". To ensure the dependability, Anney (2014) recommended the code-recode strategy. The researcher codes the same data multiple times by giving some gestation period between each of the code period. The results from all the codes are compared to see the if they are matching. The code-recode strategy was implemented in this reseach, this resulted in reduction of errors and resulted in well formulated themes. The last factor of trustworthiness in confirmability. According to Bell et al. (2019), confirmability is the act of researcher in conducting the research without his/her personal values or theoretical inclinations impacting the research. To tackle the confirmability, Anney (2014) recommended audit trials, an examination of the inquiry process to validate the data, the researcher is asked to show how the data was collected, recorded and analysed. For this research all the data collected was discussed internally and presented in seminars on how these data was recorded and analysed.

3.6.2 Authenticity

The second primary criteria for assessing a qualitative study is authenticity. Authenticity raises issues concerning the social and political impacts of research (Bell, et al., 2019). The researcher is responsible to represent the different viewpoints of the social setting to enable the research participants to understand their circumstances and thereby empowering them to change their circumstances (Bell, et al., 2019).To ensure the authenticity, the research participants have been clearly explained on the purpose of the research, the future usage of the research and also ensured that their information will remain anonymous.

3.7 Ethical Considerations

It is important to state the ethical considerations taken in this research. The four main ethical principles were considered, they are the avoidance of harm, informed consent, privacy and preventing deception (Bell, et al., 2019).

The first ethical principle is avoidance of harm. Research that involves any harm to participants is highly unacceptable. In this research, precautions were taken to not harm the participants in any ways possible. All medium of contact with research participants was through zoom according to the participant's preference and the language in the interviews were ensured to be maintained professionally. The participant's comfortability towards the research was ensured. The second major ethical consideration was informed consent. The participants were communicated everything about the research before starting the interview. There were no factors that were hidden from the participants. The next factor is the privacy. The participant's information was maintained confidential and anonymous throughout the research. Even the location was changed to regions to maintain the anonymity. The final factor was preventing deception. Deception occurs when researchers represent their research as something other than what it is. In this research, it was ensured that there is complete honesty and openness between the researcher and the participants. Moreover, the participation of the respondents was completely voluntary, and they had the privilege to withdraw from participation in the research at any point of time. These are the main factors that was focused, apart from these all-other ethical considerations were taken like maintaining the trust among the participants.

4 Findings

This section describes in detail about the analysis from nine interviews. The transcribed data is reduced to themes and sub-themes. These subcodes will include the aligned and contradicting views of the different cases. This section will also include the comparison of adopters and non-adopters.

4.1 Themes and Sub-themes

As discussed in the implementation of methodology section, the data collection was completed by conducting semi-structured interviews with nine owners/ lab managers of dental firms. The table 6 in the previous section displays the summary of the research participants including the age, size, location, and position of the respondents. The data collected from the interviews were transcribed leading to the formulation of a lengthy complex textual data.

By following thematic analysis process (data reduction, data display, and data drawing and conclusion) as stated by Alhojailan (2012) and Miles & Huberman (1994) led to the formulation of themes and sub-themes. The three major themes identified are organizational characteristics, technological factors, and environmental characteristics of AM technology. Figure 4 gives an overview of all the themes and sub-themes that were emerged from the data.

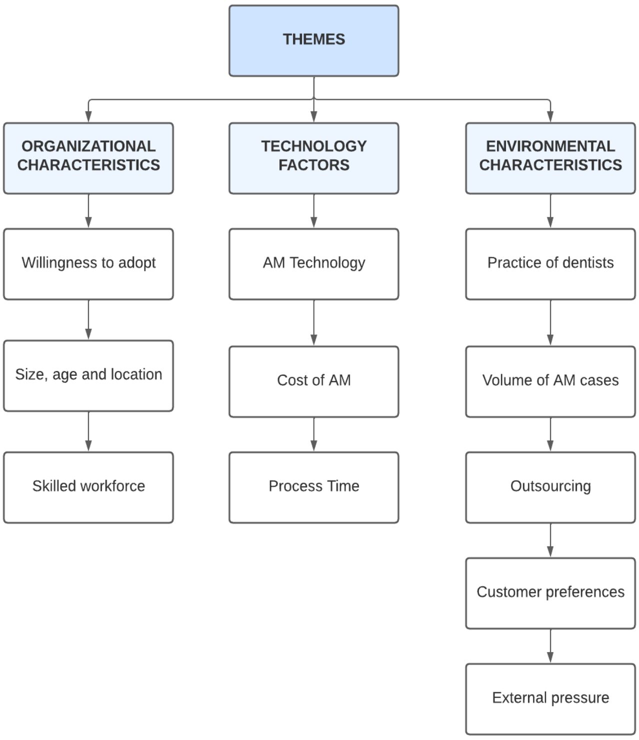

Figure 4 Themes and sub-themes

Theme 1 and Theme 3 are organizational characteristics and environmental characteristics which both aim to answer the RQ1, the characteristics of AM technology. Theme 2 is specific to RQ2. The themes are ranked based on the occurrences from the nine respondents. The findings from the two groups of respondents will be compared. The Table 5 shows the summary of the findings from the respondents including one or two highlighted quotes for every sub-theme.

Table 5 Summary of the findings

S:NO	THEME	SUB THEME	ADOPTERS	NON-ADOPTERS	SUPPORTED BY NR. OF RESPONDENTS	QUOTES
1	Organizational characteristics	Willingness to adopt	R1A, R2A, R3A, R4A	R1NA, R2NA, R3NA, R4NA, R5NA	9	"If we invest on another printer, it will definitely be used to reduce the bottle necks in production"- R4A
2		Size, age and location	R3A, R4A	R3NA, R4NA, R5NA	5	"Our company is located in a small town called ….... It is difficult to find dental technicians here" - R4NA
3		Skilled workforce	R4A	R2NA, R3NA, R4NA	4	"You need a lot of practice (to learn AM technology) which is a demanding task" - R2NA
4	Technology Factors	AM technology	R1A, R2A, R3A, R4A	R1NA, R3NA, R5NA	7	"The printer we have is very stable and their updates are pretty good" - R1A
5		Cost of AM	R1A, R4A	R1NA, R3NA, R4NA	5	"The machines (AM Machines) are too expensive"- R1NA
7		Process time	R1A, R2A, R3A	R1NA	4	"The process that takes couple of hours can be completed in couple of minutes"- R1A

Table 5 (Continued)

8	**Environmental characteristics**	Practice of dentists	R1A, R3A, R4A	R3NA, R4NA, R5NA	6	"It is decided that if the dentists invest in digital scanners, we will move to 3D printing"- R4NA
9		Volume of AM cases	R2A, R3A	R1NA, R2NA, R4NA	5	"The volume is not that big, we need more volume to be interested in buying a 3D printer"- R4NA
10		Outsourcing	R1A, R3A	R1NA, R2NA, R4NA	5	"I send the file (outsource STL file) and 2 days later I get the crown back. The workflow is easier"- R1NA
11		Customer preferences	R1A, R4A	R1NA, R3NA	4	"It is for the customers (adopting AM) and even we wanted to do this" - R1A
12		External pressure	R1A, R4A	R2NA, R5NA	4	"The whole industry have changed from conventional and digital methods, and we have to do it (adopting to AM)" - R1A

4.2 Theme 1: Organizational characteristics

As specified in Chapter-2 Literature Review, the main attribute of organizational characteristics as stated by Ukobitz (2021) is organizational readiness. Organizational readiness is stated as the firm's willingness to adopt to AM technology and experience with similar technology (Ukobitz, 2021). In this theme, the organizational characteristics such as size, age of the firm, the workforce will be studied.

On analysing the data, the codes with the most occurrences were considered. This resulted in the formulation of three sub-themes as shown in Figure 8 and Table 7. Out of all the most frequent sub-theme was Willingness to adopt.

4.2.1 Willingness to adopt

This sub-theme was discussed by all the respondents, including adopters and non-adopters. The findings show that almost all the adopters of AM technology were willing to expand their current technology due to certain factors. The same was applicable for the non-adopters, however there was one respondent who strongly believes that the company will not adopt to AM technology.

In the case of adopters, the respondents were ready to invest on another printer, in order to achieve a reduction in overtime of the previous printer, reduction of bottle necks in production, separate printer for printing splints. One company R2A was willing to invest on another printer provided that the volume of AM cases increases.

Similarly in the case of non-adopters, most of them were planning to invest on a printer. There were however some considerations that was to be met for them to adopt to AM technology. One company R3NA strongly denied the adoption of AM technology, the reasons being that the respondent likes manufacturing in the old methods and his customers were happy with that and states that it makes the respondent unique by using the old methods. The respondent also added that the model that is made by the AM methods haven't nailed it yet.

> "Many of my customers do say that they have tried printed splints and they don't like them because they have problem with fit, they (customers) prefer the way I work (conventional methods)"- Company R3NA

One company R1NA had many challenges in adopting to AM technology, however the respondent was ready to adopt if he needs to. Two companies R2NA and R4NA were ready to invest on a 3D printer if there is an increase in number of AM cases, this was a similar statement by the company R2A. The company R5NA responded that the company is planning to invest on a 3D printer as it is the only way for making models with intraoral scanned impressions.

4.2.2 Size, age, and location of the firm

The factors of size, age, and location of the firm are specified as one sub-theme because when considered separately there are a smaller number of respondents. However, the size, age, and location will be compared separately from the statements and data given by the respondents.

Some of the respondents from both adopters and non-adopters discussed size of the company to providing constraints to technology adoption. The two companies R3A and R4A stated that they are small dental labs. The company R3A discussed in specific to the adoption of CoCr (Cobalt Chrome) laser printer and stated that they are built for huge production centres and not small dental labs.

> "CoCr needs laser printers which are not required for small dental labs, they are built for huge production centres"- Company R3A

The company R4A responded positively that the printer they own is versatile and perfect for small labs. In the case of non-adopters, size was a constraint to adopt to this technology. The company R3NA responded that the company could not adopt to this technology because they are a small company working full days and evenings and finding a time to learn AM technology is difficult. The company R4NA also responded similarly but did not emphasise more on this aspect, the respondent stated that they do not have a 3D printer yet and the reason being that they are not a big company. The same respondent also talked about location as well, he/she was the only respondent to give a remark based on the location. However, that there was only one respondent, it deemed necessary to talk about the location as sub-theme skilled workforce could be inter-related. The respondent stated that the location the company is located is a small place and finding dental technicians with degree is not very easy.

Coming to the age of the firm, there were no direct statements from the respondents who talked about the age of the companies. However, the respondents were all questioned on when their firm started, and the information was consolidated. From the consolidated data there was an interesting finding. Table 6 summarizes the age of the firms or the year they started. From the table it can be noted that all the four companies who have adopted AM technology are the new firms which originated in 2015 or later. Whereas, in the case of non-adopters most of the companies have been established for a very long time. At least three of the firms were established in 1980s and the rest two were established in 2012 and 2015 correspondingly. Detailed discussion on the age of the firms will be conducted in the discussion section.

Table 6 Age of the firms

S.NO	Company	Age of the company	Nature of the company
1	R1A	Since 2015	Adopter
2	R2A	Since 2019	Adopter
3	R3A	Since 2018	Adopter
4	R4A	Since 2019	Adopter
5	R1NA	Since 1985	Non-Adopter
6	R2NA	Since 1984	Non-Adopter
7	R3NA	Since 2015	Non-Adopter
8	R4NA	Since 2012	Non-Adopter
9	R5NA	Since 1985	Non-Adopter

4.2.3 Skilled workforce

A few respondents from both adopters and non-adopters have raised the skilled workforce aspect. When considering the adopters of AM technology, one company R4A talked about his experience of acquiring the skill to learn AM technology when the technology was new. The respondent stated that there were a lot of settings and there were lots of trial and error in the beginning and it was difficult to learn on what is going on, however he also mentioned that after learning the technology it was very easy for the respondent. The respondent adds that there is a learning curve which is going to be difficult and scary for the new adopters of AM technology.

> "There is a learning curve. It is going to be difficult. It's a whole new technology. It's a scary jump after that they won't look back" – Company R4A

In the case of non-adopters, a majority of respondents discussed learning the technology as a barrier and as well described the requirement of skilled force as a constraint. R2NA and R3NA both stated that they have been in this field for a long time and are used to the old methods of manufacturing and acquiring this new skill for AM is a demanding task. R4NA specifies the location as a constraint to find skilled workforce, stating that it is very difficult to find lab technicians with a degree in small towns.

4.3 Theme 2: Technology factors

The second theme technology factors correspond to how the companies perceived AM technology. The analysis resulted in the formulation of a few sub-themes, however since there was less frequency for those smaller sub-themes, they were combined to formulate three sub-themes, AM technology, cost of AM and processing time.

4.3.1 AM technology

The second most frequently discussed sub-theme after ‘Willingness to adopt’ was ‘use of AM technology’. In this sub-theme the adopters and non-adopters compared their thoughts on the use of AM technology.

Starting with the adopters, all the four adopters stated their views on the innovative AM technology, a majority of the adopters seem to be satisfied with the use of AM technology. According to company R1A, the AM technology is great and affordable right now, with stable performance and pretty good updates. The respondent also mentioned that the technology was easier than milling process. Company R3A felt that adoption of 3D printer has given her the liberty to produce parts in her own schedule without depending on external agencies. Another company R4A stated that the AM technology has resulted in time efficiency, material efficiency, increased accuracy, and detailing. However, R2A perceived a negative view on AM technology stating that it is slower process than milling machine.

> “There is not much waste with AM. Time efficiency, material efficiency, accuracy (acquired with AM technology)” – R4A

Most of the non-adopters also discussed their views. Two companies R1NA and R5NA both shared that the workflow will be easier with AM technology, however there will be a requirement for a change in the workflow. There was a contradicting view of one company R3NA stressing that AM technology is brilliant, and it is the future, however he states that in the case of splints they lack in quality and are usually of not proper fit.

4.3.2 Cost of AM technology

Most of the respondents from either of the groups have discussed about the cost of AM technology. Yet again there were varying views from adopters and non-adopters of AM technology.

According to the adopters of AM technology, the companies R1A and R4A both support the statements that AM technology has become affordable over the years. One company R1A stated that the big machinery costs millions of euros, however the affordable machines have reduced the cost of outsourcing and credited that the machines are affordable right now. The company R4A stated that machines have become more efficient and cheaper.

> “If we do not have a printer, it is more cost for us. That is why we bought a printer and we are using it every day……it is more easier than milling and it costs less (sentence slightly modified due to language issues)” – Company R1A

The non-adopters of AM technology had a completely different view with regards to cost of the machines. Most of the companies R1NA, R3NA and R4NA called out that the machines are very expensive. Two companies R1NA and R4NA stated that money is one of the main reasons for not adopting to technology. The company R3NA stated that the big machines are really expensive, and he will not be able to sell the best products if they do not buy a good printer.

4.3.3 Process Time

A few respondents discussed on the perspective of process time of AM technology. Most of the respondents who have discussed about the processing times talked in the favour of process time, however one respondent who is an adopter had a different view. The companies who have discussed about process time include two adopters and one non-adopter. The companies R1A, R4A and R1NA stated their same point that AM is faster. The company R1A stated that the process that took couple of days is now completed in couple of hours. The company R4A also stated that with the use of AM technology, time efficiency can be achieved as there is a possibility for dentists to have their own printers and the designing can be done in the lab and sent back to the dentists and the patient could receive the part in less than half hour. The company R1NA who outsources some parts to be printed with AM technology credited these statements by adding that through AM it was possible to produce 20 to 25 crowns (dental crowns) each day. All these statements favour the reduction of process time of AM process.

However, with respect to the process times of AM technology, one adopter R2A stated that sometimes the machines are very slow and take around 6 hours to 8 hours and mentioned it to be slower than milling machines. The reasons for this contradicting statement could be for any number of factors, this will be discussed further in the discussion section.

> "The problem is sometimes it is not fast. Sometimes it takes 6 to 8 hours. It is slower than milling machine"-R2A

4.4 Theme 3: Environmental characteristics

The theme-3 focuses on all the external factors that lead to the adoption and non-adoption of AM. All the factors were analysed and listed; the most frequently analysed codes were considered as the sub-themes under the factors of AM adoption.

4.4.1 Practice of dentists

One of the most interesting findings from the data collection was the practice of dentists. This sub-theme was the third most frequently discussed topic by the nine cases.

Both adopters and non-adopters had different views on this aspect, this makes it difficult to compare the groups. Some of the adopters and non-adopters had similar views. The companies R1A and R5NA state that the dentists have equipped with the intra-oral scan technology, and it is necessary to adopt to 3D printing as that is the only way to print working models through intra-oral scanned impressions. Whereas companies R3A, R3NA and R4NA state that very few dentists work with intra-oral scanners. One company R4NA state that currently there are only 4 or 5 dentist customers in his region who have digital scanners and hence there is less volume of cases. They further state that once the dentists start using intra-oral scanners there will be more adopters of AM technology.

One final and interesting view in this sub-theme is from company R4A. The respondent stated that they have invested on intra-oral scanners, and they provide it to their customers/dentists who have not used scanning before. They stated that their customers do not want to go back to taking impressions and they have invested on intra-oral scanners. In this way they have promoted the adoption of AM technology. Company R4A also stated that the reason that the company adopted AM technology was because of the large influx of digital impressions.

> "The first drive was when intraoral scanning became popular with customers, there was a larger influx of digital impressions and we wanted to work from that….This technology is a necessity for me rather than an option"- Company R4A

4.4.2 Volume of AM cases

In the context of volume of AM cases, most of the companies who have stated their views on volume of AM cases were alike, this includes both the adopters and non-adopters of AM technology.

The majority of the respondents stated that there are a smaller number of AM cases available currently, one of the reasons being the dentists practice as discussed before, thus only a few volumes of cases arise. Since there are very few cases involving STL files most of the companies outsource their requests. However, few of the respondents are ready to invest on a 3D printer when there is an increase in the volume of AM cases.

> "If they(customers) have extra job, I think I need to buy (additional 3D printer) but most of my customers use classic methods (wax impressions). In future depending on request, I will buy 2 to 3 machines"- Company R2A

4.4.3 Outsourcing

Another factor stated by most of the respondents were outsourcing. The adopters of AM technology had the same views on the reason for outsourcing, whereas in the case of non-adopters their reasons varied among the respondents.

Some of the adopters of AM technology (Companies R1A and R3A) stated that they outsource their requests to external organizations, this request is sent only when the customers require with Ti (Titanium) or Co-Cr (Cobalt Chrome) or any other metals in that case. The reason being that they have printers only capable of printing plastic resins and for printing with metals will require huge machinery which is expensive.

> "We don't have big machinery; it costs millions of euros. It is mostly Ti and Co-Cr (outsourcing). We print only plastics" – R1A

In the case of the non-adopters, their reasons for outsourcing varied. The company R1NA stated that machines are really expensive and there are only less cases for AM, therefore he prefers to send the products for outsourcing as the workflow is easier. The respondent R2NA felt that it was better to outsource as it was difficult for the respondent to learn about AM technology and the final respondent R4NA stated that it is better to outsource as there is less volume of AM requests.

4.4.4 Customer preference

Few of the respondents discussed about the customer preferences. The adopters stated on how their customers were a reason to adopt to AM and resulted in an interesting finding. In the case of non-adopters, the respondents point out different views of their customer segment.

Beginning with the group of adopters, company R1A states that they have adopted to AM technology both for the customers and for themselves. One company R4A, points out that they do it for the customers as well. They for instance, helped a customer in Norway to setup a 3D printer in their clinic. The company does the work in the CAD and the customer prints it out when the patient sits in the clinic. For example, a temporary bridge could be printed in less than half hour, providing a win-win situation especially for the patients, the company benefits by doing the work in the CAD for the clinicians and similarly they invested on intra-oral scanners for the customers, this was mentioned in the dental practices sub-theme.

In the group of non-adopters, one company R1NA stated that the customer preferences do not matter because the customers do not care If the company casts or prints, in fact the customers are unaware that the metal constructions are printed through outsource. According to company R3NA, the customers prefer the way he/she works, i.e., sticking to the conventional methods. The respondent states that the customers are not happy with the splints manufactured by AM because of the fit, they are either too loose or too tight.

4.4.5 External pressure

The last sub-theme is external pressure. Some of the respondents from both the groups stated that competition is a factor for adopting to AM technology. There were interesting findings stated by both adopters and non-adopters on how the dental industry has evolved.

Considering the adopters of AM technology, the company R1A stated that whole industry has changed from conventional to digital methods and they had to adopt to AM to keep up with technology. The respondent also added that the industry has rapidly changed and if we don’t adopt then they will lose the market share. One company R4A stated that the main reason that the printers have evolved so much is because of competition. The process of sending out to companies, the cost involved, and the time involved became a question of competition. The need of improved precision and material efficiency were due to competition.

For non-adopters of AM technology, company R2NA stated that the main reason that he wants to adopt to AM technology is because everything is going digital, and it is also needed to develop yourself and keeping up with the market. One company R5NA pointed out that if they do not adopt to AM soon then their customers will send their requests to other labs, and they will indeed lose their market share.

> "I'm planning to have it because you must develop yourself and go with the future. Everything is going digital, and you need it…"- Company R2NA

The next section is the implementation of TOE framework. Since there are two groups to be studied in the framework. The results generated from the two groups will be analysed differently.

5 Implementation of TOE Framework

In TOE framework, the three crucial factors influence the adoption of AM technology, this includes the technological factors, organizational factors, and the environmental factors. To discuss the TOE framework, each of the factors will be listed and analysed if it is a driver or barrier for AM adoption.

5.1 Technological factors

The technology factors are the factors in which the AM technology has impacted its adoption. The factors related to technology such as the use, the time efficiency, the cost and so on. The only technological factor that is applicable for non-adopters is the cost of AM machines. The other technological factors involve the usage of AM technology. Since none of the non-adopters have incorporated AM technology in their production, they will not have anything to contribute in terms of technological factors, however the general factors such as environmental impact can be related to non-adopters as well.

5.1.1 AM technology, ease of use

From the adopters of AM technology, it can be learnt that at least for most of the adopters it was difficult in the beginning, there were questions such as which system to buy, what can we do with this technology, how much time and money needs to be spent, what are the settings, how does the technology work, how should the workflow be adjusted. Irrespective of these questions, all the respondents stated that the technology worked great once they got all the questions figured. They also stated that there is a learning curve, and it is going to be difficult but once they take the scary jump they will not look back. From the previous research, Marak et al. (2019) stated that AM technology is easy to use. However, the other literatures pointed out that software packages are complicated (Garza, 2007; Gao, et al., 2015). To discuss on all the above findings, it is agreeable that the learning curve is going to be demanding and there is going to be difficulty in the initial days but most of them also stated that the technology is becoming easier. Due to the contradicting views between the respondents and existing research it can be stated that the use of AM technology is a driver to AM adoption with respect to the adopters.

The use of AM technology is not applicable for the non-adopters of AM technology as they do not have any experience of AM technology. Furthermore, the ease of use could not be supported by previous research as it requires the feel and actual experience of using AM technology, it is not a common factor. Moreover, the usage of AM technology differs between every individual and cannot be generalized, hence the ease of use of AM technology is marked as not applicable.

5.1.2 Process time, acceleration time to market, simplified supply chain, mass customization

This can be discussed by analysing both the existing research and the statements from companies. With regards to the job performance, several respondents have stated that AM has increased the performance with respect to the production. The adopters of AM technology stated that the overall process became a lot faster, and it has in fact reduced the bottle necks in production. Furthermore, they are ready to invest on another printer to further breakdown the bottle necks, increase the efficiency of production and to print specific parts separately as there will not be need of frequent change in materials. It is clear from the research that the AM technology has simplified the supply chain and accelerated the time for the market (Ukobitz, 2021; Marak, et al., 2019). Further Thompson et al. (2017) pointed out that the AM technology possess a longer production time (Thompson, et al., 2017). However, from the findings it can be seen that company R2A stated that the 3D printers are not fast enough, corresponding to the speed of the machines, there could be several factors which could have slowed down such as the type of the machines, irregular maintenance, insufficient knowledge about the machines and so on. However, the point is that one respondent's experience on the speed of the machine could not make a negative contribution on overall adoption of AM technology. A majority have stated that the system is faster. Furthermore, from the findings of literatures, many authors have supported the statement that AM has accelerated the time to the market (Refer Acceleration of time to market in chapter 2) (Ukobitz, 2021; Gao, et al., 2015; Schniederjans & Yalcin, 2018). Therefore, the process time or the performance of the machines can be stated as a driver to AM adoption.

The process time is not applicable for the non-adopters of AM technology as they do not have any experience of AM technology. The process time differs with many factors such as the type of printer, the product that needs to be printed and so on. Therefore, the process time cannot be supported by previous research and requires the experience of AM technology from the research participant. Hence, the process time is marked as not applicable for the non-adopters of AM technology.

5.1.3 Cost of AM, investment costs

To discuss the cost of AM technology, there were more negative perceptions on the cost of the AM machine making it one of the major barriers. The adopters of AM technology stated that there are wide range of printers available which are from moderate price to expensive machines. The respondents stated that the price of the machines have lowered over the years and the investment of AM technology have led to the reduction of outsourcing costs. However, some companies stated that the big machineries are expensive. According to the adopters of AM technology the cost was not a major problem.

From the previous research, the authors called that the investment costs are the most dominant barrier on the adoption of AM technology, the cost of machines, materials and maintenance are high (Ukobitz, 2021; Schniederjans & Yalcin, 2018). However, there were no evidence on the previous research on the existing findings to state that the cost is a barrier for adopters of AM technology. Hence cost is neither a driver or barrier for the adopters of AM technology, as the small machines work efficiently and are affordable according to the adopters.

The non-adopters of AM technology have stated that the AM machines are expensive and have also stressed that the cost of AM machines was one of their main reasons for not adopting to this technology. In the case of non-adopters, the previous research and the new findings from non-adopters show that cost of AM technology is a clear barrier to technology adoption with respect to non-adopters.

5.1.4 Technological maturity

The technology maturity refers to the standardization of AM technology and the output quality. Starting with the adopters, most of them stated that there are wide number of options available, and it was a difficult decision to choose the appropriate printer. The printer that the adopter's population in this case use are capable of printing plastic resins only. To incorporate other materials the respondents must invest in another printer as there is no uniform standardization of AM technology. In terms of quality of the product they mentioned that initially it was hard to get good quality but now the printers have changed a lot and produces parts with good quality.

The previous research state that the lack of standardization of AM process has made it challenging to adopt AM technology, moreover regarding the quality, more layers are required in build to obtain good quality this means that the production time will increase (Ukobitz, 2021; Gao, et al., 2015). It can be concluded from the previous research and existing findings that the standardization of AM technology is a barrier but as the adopters favored the improved quality of AM products, the quality of AM products is not listed as a barrier.

The technological maturity is not applicable for the non-adopters of AM technology as they do not have any experience of AM technology. The market is evolving and the current situation of market in terms of AM technology can be analysed only if they are using AM technology. Irrespective of the previous research stating that there is a lack of standardization, it cannot be supported in the case of non-adopters of AM technology as the experience is required for analysing the standardization of AM technology and the output quality and hence it is marked as not applicable.

5.1.5 Reduced material waste, environmental impact

The next factor is regarding the environmental impact. It is generally perceived that AM uses very less materials than the subtractive methods as AM is an addition process produced layer by layer.

On looking into the adopter's opinion, they stated that material efficiency could be obtained with the use of AM technology. However, from the literatures, many authors discussed about the positive environmental impact of using AM technology. The authors specified that with AM technology it was possible to reuse the materials, reduce raw materials and there is less energy consumption with the use of AM (Schniederjans & Yalcin, 2018; Marak, et al., 2019; Gao, et al., 2015). Thus, there is a positive attitude on AM's ability to reduce waste and reduce environmental impact. In line with this, findings from this study on adopters show clearly that environmental impact is a driver.

The reduced material waste is not applicable for the non-adopters of AM technology as they do not have any experience of AM technology. However irrespective of the non-adopters not having experience in AM technology, there is a potential for the non-adopters to adopt to AM technology on learning the advantages of AM technology towards the environment from the previous research. This could be a driving force for technology adoption among the non-adopters of AM technology.

5.1.6 Material maturity

The material maturity is the availability of materials for AM productions. On regards to materials, the adopters of AM technology have stated that currently they are only able to print one material at a time, and they need to keep changing the materials when they must change the production part to be printed. In the case of splints, transparent plastic resin is used and in the case of model's different color plastic resins are used. This makes it stressful for the technicians and they feel the need for another printer to make the process easy and use two different printers for each of their products. This increases the cost of investment and the running costs as two or more printers will be used. Existing research support that there is a limitation of using only one material at a time (Dwivedi, et al., 2016). However, Kretzschmar, et al. (2018), stated that there is research on multi-materials AM systems but there are still questions on the uncertainty of behaviour at material interfaces.

AM is a growing technology and there are improvements on every update and the problem of one material at a time might soon fade away. However, currently the previous research and existing findings of adopters state the limitations of current availability of materials and hence can be marked as a barrier to AM adoption.

The material maturity is not applicable for the non-adopters of AM technology as they do not have any experience of AM technology. As stated earlier that there are improvements on every update, the findings from previous research cannot be used to support the analysis of material maturity in terms of non-adopters and hence it is marked as not applicable.

Table 7 includes the summary and the result of technological factors on AM technology. The table shows that three of the factors are drivers to AM technology and two factors act as barriers to AM adoption and one factor is listed neither as a barrier or driver for the adopters of AM technology. However, from adopter's technology perspective, it can be noted that the drivers outweigh the barriers of AM adoption.

Table 7 Rating of technological factors

S.NO	TECHNOLOGICAL FACTORS	ADOPTERS	NON-ADOPTERS
1	Use of AM technology	Driver	NA
2	Process time	Driver	NA
3	Cost of AM	Neither Driver nor Barrier	Barrier
4	AM Standardization	Barrier	NA
5	Reduced environmental impact	Driver	Driver
6	Material maturity	Barrier	NA

5.2 Organizational factors

The organizational factors are the factors within the organization that favours or prevents AM adoption.

5.2.1 Willingness to adopt

Most of the adopters of AM technology show a great willingness to adopt or expand AM technology. Although their willingness to adopt was based on some other factors.

With regards to the adopters of AM technology, the respondents were willing to invest on additional AM machines to obtain more productivity and easier workflow. There is not many literatures pertaining to willingness to adopt, however Ukobitz (2021) states that it is utmost important for successful organizational technology adoption. From all the statements it can be mentioned that 'willingness to adopt' is a driver for AM technology adoption.

Most of non-adopters of AM technology show a great willingness to adopt AM technology. Although their willingness to adopt was based on some other factors. The non-adopters of AM were willing to adopt to AM technology provided that the volume of AM cases increases and due to changes in dental practices of adopting to intraoral scanners. As mentioned earlier, Ukobitz (2021) states that it is utmost important for successful organizational technology adoption. From the findings and the previous literatures pertaining to willingness to adopt it can be concluded that willingness to adopt is a driver to AM adoption.

5.2.2 Skilled workforce

The next factor is skilled workforce or availability of resources, the adopters of AM talked about their experience in acquiring the skill to adopt to AM technology and stated that the learning period was difficult and after that it was easy. The previous research also state that there is a lack of skill and training is required to get the full benefit of AM technology, furthermore the resources are hesitant to adopt as they have the fear of losing jobs because of AM technology (Ukobitz, 2021; Choudhary, et al., 2021; Mellor, et al., 2013).

In general, learning something new or adopting to a new technology is often not comfortable and there is a learning curve which will be difficult as stated by company R4A and once the skill is acquired then the process gets relatively simple. As there is willingness to adopt, there might be a potential for the respondents to acquire the necessary skill. However, since many statements support the lack of skilled workforce, the skilled force can be marked as a barrier of technology adoption.

In terms of non-adopters, they stated there is a requirement to acquire the skill. The non-adopters stated that it was a demanding task to acquire the skill and finding skilled resources was difficult. The statements from previous research as stated above and current findings from non-adopters of AM show that finding skilled workforce is essential for adopting to AM technology and hence can be mentioned as a barrier.

5.2.3 Structure and alignment of the organization

The adopters stated that they had to plan out everything, like fixing the budget, the need for this technology, the plans of execution of technology. It took two years to restructure the organization and decide to adopt to AM technology and now the respondent says that the workflow is very smooth, the production line have got better, and they are pleased with it. Furthermore, the existing research state that the organizations should change their work practice, structure, jobs, and practice for successful adoption of AM technology (Mellor, et al., 2013). All the statements predict that there is a requirement to restructure and align the organization for smoother adoption. Although the result of restructuring the organization will result in smoother adoption, it takes a lot of effort to restructure and align the organization, hence it can be marked as a barrier to technology adoption.

The non-adopters stated that there will be a requirement of resources with skills and changes in the workflow. From the findings and previous literature, it can be stated that structure and alignment of the organization can be marked as a barrier to AM technology from the non-adopters.

Table 8 summarizes the results based on organizational factors. From the table it is noted that there is one driver and two barriers in terms of organizational adoption. The barriers are more than the drivers in this case of both adopters and non-adopters of AM technology.

Table 8 Rating of organizational factors

S.NO	**ORGANIZATIONAL FACTORS**	ADOPTERS	NON-ADOPTERS
1	Willingness to adopt/expand	Driver	Driver
2	Skilled workforce	Barrier	Barrier
3	Structure and alignment	Barrier	Barrier

5.3 Environmental factors

Environmental factors are the external factors that are not influenced by the organization or the technology itself. It is based on how the society impacts the adoption.

5.3.1 Practice of dentists

As stated in the findings, the company R4A stated that the main reason that they have adopted is because of the large flux of digital impressions. Company R1A also agree that dentists have equipped with intra-oral scanners, and it was necessary to adopt to AM technology. However, R3A stated that a very few dentists work with intra-oral scanners. The previous research point out that some of the dentists have not adopted intra-oral scanners because of the high investment and less number of cases. However, with intraoral there are benefits such as reduced discomfort and time efficiency (Ciulla, 2020; Christopoulou, et al., 2022). From the current findings and existing research, the practice of dentists can be a barrier or a driver to technology adoption depending on the adoption of intra-oral scans.

In the case of non-adopters of AM technology, the company R3NA stated that dentists are equipped with intra-oral scanners, whereas company R4NA state that there are very few dentists with intra-oral scanners. Since the company has not adopted AM technology because of the availability of dentists equipped with intra oral scanners. Practice of dentists is barrier for the non-adopters of AM technology.

5.3.2 Volume of AM cases

Coming to the factor of volume of AM cases, the adopters agree that currently there are a smaller number of requests specific to AM. However, they predict that the cases will raise up over the years. The research with this aspect were not found. It can be stated that the low number of AM cases is a barrier to AM adoption within adopters of AM technology.

The non-adopters also stated that there are a smaller number of requests specific to AM and are predicted to raise up over the years, based on the volume of AM cases the non-adopters were ready to adopt. As currently there are less number of cases, it is a barrier as well for non-adopters of AM technology.

5.3.3 Customer preferences

In the case of adopters, the respondents stated that customers were one of the factors that they have adopted AM technology and the companies stated that if they don't adopt then the customers will go to the companies where they have adopted. On compiling the statements there is evidence that customer preferences have impacted AM on some extent at least. The customer preferences can be listed as a driver for technology adoption.

The non-adopters of AM technology stated that the customers do not mind on what technology they produce the parts and another company R3NA stated that the customers prefer the way he works. From the above two statements, it can be seen that the customer preference is neither a barrier nor driver for adoption of AM technology.

5.3.4 External pressure

Most of the adopters stated external pressure is a major factor for technology adoption. They stated that they had to adopt as the market is changing and it is essential to develop yourself to sustain in the market.

The existing research also supported, stating that the firms are forced to adopt due to competitive pressure (Yeh & Chen, 2018), which has positive implications on technology adoption. Since all the statements support external pressure as a strong factor for AM adoption it is a driver of AM technology.

The non-adopters stated that the main reason that they are planning to adopt AM technology is because everything is going digital and stated that if they do not adopt soon then they will lose the market share. External pressure can be concluded as a driver for AM technology.

Table 9 summarizes all the environmental factors affecting AM adoption. There drivers of AM technology are more than its barriers in the case of adopters, whereas for non-adopters there are more barriers than the drivers.

Table 9 Environmental factors TOE

S.NO	ENVIRONMENTAL FACTORS	ADOPTERS	NON-ADOPTERS
1	Practice of dentists	Neither barrier nor driver	Barrier
2	Volume of AM cases	Barrier	Barrier
3	Customer preferences	Driver	Neither barrier nor driver
4	External pressure	Driver	Driver

5.4 Outcome of TOE framework

The outcome of TOE framework with respect to adopters resulted in the technological and environmental factors having more drivers than the barriers showing that the advantages of AM technology outweigh the limitations. However, in the case of organizational factors the barriers were more than the drivers of AM technology. The implication from the TOE framework with respect to adopters of AM technology is that there are a number of factors that drive the adoption of AM technology.

However, in the case of non-adopters, the number of barriers is more than the drivers of AM technology, showing that non-adopters are still hesitant to adopt to AM technology due to the several factors as stated before.

6 Discussion

This section discusses the results by interrupting the theoretical frameworks, data analysis and literature review. The research question will also be answered in this section.

6.1 RQ: Characteristics of adopters and non-adopters.

The organizational characteristics, environmental characteristics and technological characteristics related to the adoption of AM technology in dental technology companies are summarized below.

6.1.1 Organizational characteristics of adopters and non-adopters

Table 10 comprises the summary of the organizational characteristics of both adopters and non-adopters and illustrates the comparison between the two groups.

Table 10 Organizational characteristics of adopters and non-adopters

S.NO	ORGANIZATIONAL CHARACTERISTICS	ADOPTERS	NON-ADOPTERS
1	Willingness to adopt/expand	Great willingness to expand	Moderate to good willingness to adopt
2	Experience of AM technology	Majority results show positive experience of AM technology	-
3	Size of the firm	Mostly small- based on number of resources and firm size	Mostly small- based on number of resources and firm size
4	Age of the firm	Established from 2015 or later	Established between 1984-2015
5	Location of the firm	Adopted in both small and big towns	Not affected by location, small towns and big towns did not adopt
6	Skilled workforce/ education / training	Difficulty in acquiring the skill in the beginning	Difficulty in finding skilled technicians
7	Structure & Alignment	Required restructuring	Might affect the workflow

To recollect, the problematization of the AM technology in dentistry is that the existing research reflect more on the intent of adoption rather than the action of adoption. One of the purposes of this research was to study the experience of adopters who have implemented AM technology in their production methods, and it was stated that this will be done by comparing the characteristics of adopters and non-adopters, which should result in insights on preparing firms for technology adoption. Additionally, as Ukobitz (2021) stated that organizational readiness (willingness to adopt and top-management experience) are the crucial drivers to adoption. When it comes to willingness to adopt, what can be learnt from the adopters is that the market has changed, and they had to adopt to this technology. Moreover, pertaining to the facts of the results of AM technology made them willing to expand their machines to gain more advantages of AM technology, as stated in the table 12 there is evidence that there is a great willingness to further expand their production units by buying additional printers to serve different purposes. When comparing the adopters with the non-adopters, most of the non-adopters were willing to adopt if the market evolves, that is the cost of the 3D printer comes down and the volume of AM cases raise up. To finalize the discussion on aspect of willingness, from the findings of Theme-1 and the TOE framework, it can be stated that the adopters show a greater willingness to expand their AM technology, whereas the non-adopters are willing to adopt however they are withheld by some external factors.

The second important characteristics is experience of top management, Ukobitz (2021) states that this characteristic is of utmost importance for successful organization adoption. As stated by Chatzoglou & Michailidou (2019), the experience of managers is related to the attitude and perceived ease of use of the technology. Many factors from the sub-themes ‘Use of AM technology’, ‘Process time’ and all the frameworks show that most of the adopters have a positive experience on AM technology. Chatzoglou & Michailidou (2019) stated when the manager finds the positive consequences of using AM technology, then the individual will have greater intention to adopt AM technology. From the adopter’s perspective there is a good opinion on the willingness to adopt as well as good experience with AM technology. These imply that these factors could impact the non-adopters and be a crucial driver for technology adopters. Coming to the size, age, and location of the firm. There are no distinctive features that differ between the two groups. This is because the smaller sample size could not support the conclusions on this aspect. However, as stated earlier there is a probability that the new firms are more likely to adopt as they start with the AM technology and there is no need for them to restructure or align to adopt to this technology. Regarding the size of the companies, Kianian et al. (2019) stated that the Swedish SMEs are the dominant users of AM technology. In our findings, all the firms were lesser than 50 employees making them listed as small enterprises. If SMEs remain to be the dominant users of AM as Kianian et al. (2019) mentioned, then there is a greater probability that the non-adopters in this research will adopt in the future.

The next organizational characteristics is skilled workforce. What could be learnt from the adopters is that when they adopted the new technology there was a difficulty in upgrading the skills and now, they state it is a lot simpler. However, the non-adopters find it difficult to learn this new technology and finding the right resources have become difficult. This correlates with the statements of Choudhary et al. (2021) stating that there is a lack of skilled workforce and education and there is a requirement for training. Finally, the adopters mention that there is a requirement to restructure the organizations to have a smoother workflow and the non-adopters state it as a challenge to change the workflow.

On studying the organizational characteristics of adopters of AM technology, the non-adopters could learn that the existing adopters have a good view on the experience of AM technology. Size, age, and location of AM may not be constraints for adoption as some of the smaller firms in smaller towns have adopted to AM. It will be difficult to acquire the skills or find skilled resources but once you understand the machine the outcomes are great and finally there will be a requirement for restructuring the organization, in doing so it can make the adoption a lot easier and making the workflow a lot simpler. As stated in the TOE framework, although there are more barriers on organizational characteristics, the market is evolving and there are lots of graduates specializing in Additive manufacturing and new firms can establish AM without the need to restructure, thus removing the barriers in terms of organizational characteristics in the near future.

6.1.2 Environmental characteristics of adopters and non-adopters

Table 11 comprises the summary of the organizational characteristics of both adopters and non-adopters and also illustrates the comparison between the two groups.

Table 11 Environmental characteristics discussion

S.NO	Environmental Characteristics	Adopters	Non-Adopters
1	Practice of dentists	Some dentists are equipped with intra-oral scanners	Some dentists are equipped with intra-oral scanners
2	Volume of AM requests	Less volume	Less volume
3	Customer preferences	Do it for customers and company	Customers do not prefer/ Customers prefer alternate methods
4	External pressure	Keeping up with market	Keeping up with market

Starting with the practice of dentists, the adopters and non-adopters stated that a few dentists are equipped with intra-oral scanners and others mentioned that they had to step into AM as there was a great inflow of digital impressions. The reasons of these varied opinions could be several factors such as the location of the firm, the number of dentists within the scope of the firm, the age of the dentists and so on. As stated in Chapter 2.2.2., Christopoulou et al. (2022) mentioned that the older clinicians with lesser experience to digital technology might face difficulties with the device and software. This could be one potential reason. The other reasons could be as stated by Ciulla (2020), the high initial investment and the number of practices, this could further relate to the factors of size and location the dentists are located. The next environmental characteristics are the volume of the cases, this can be related to the practice of dentists, because if the dentists use intra-oral scanners, then STL files will be generated and thus 3D printing will be needed. It can be said that the practice of dentists is directly proportional to the volume of cases. Since there are a smaller number of dentists with intra-oral scanners, the number of cases for AM are relatively less.

The next environmental characteristic is the customer preference. The adopters have stated that they have invested the 3D printers for the customers and for the benefit of the company. Whereas the non-adopters stated that the customers do not have any preference on how the products must be printed and some stated that customers preferred the older ways and not the AM. This has prevented the non-adopters to adopt to AM technology as they are not motivated by the customers to invest in AM technology. The last environmental characteristic is the external pressure. Both adopters and non-adopters have talked about how the market has changed from conventional to digital methods. The fear of loosing the market and the pressure to keep up with existing technology has been the drivers of technology adoption. The statement of Jeyaraj et al. (2006) can be seen true in this case, the authors expressed that the positive implication of technology adoption is competitive pressure. As the advantages can be seen from AM technology in terms of supply chain, inventory and operational efficiency as stated by Yeh & Chen (2018) are due to competitive pressure. The firms have therefore been forced to adopt to AM technology to achieve competitive advantage through innovation (Zhu, et al., 2006).

The environmental characteristics are the attributes that can directly influence the adoption of AM technology. The more the practice of dentists becomes digital, the more the volume of cases, the more the change in customer preferences, resulting more in competition and thereby resulting in adoption of AM technology.

6.1.3 Technological characteristics of adopters and non-adopters

Table 12 illustrates the summary of technological characteristics for both adopters and non-adopters of AM technology and shows the comparison of results from both the groups. However, it is to be noted that most of the characteristics are denoted as NA (not applicable) for the non-adopters as they have not used the technology yet.

Table 12 Technological characteristics discussion

S.NO	Technological Characteristics	Adopters	Non-Adopters
1	Ease of use	Difficult at the beginning	NA
3	Supply chain	Reduced bottlenecks	NA
4	Process time	Overall process became faster	NA
5	Reduced environmental impact	Increased material efficiency	NA
6	Cost of AM machine	Not a major problem	Cost is a one of the main reasons for not adopting to AM technology.
7	AM standardization	No uniform standardization	NA
8	Material maturity	Able to print only one material at a time	NA

These characteristics were compiled after discussing the impact of each of these factors in the TOE framework. The recognized technological characteristics among them are ease of use, supply chain, time to market or process time showing that one of the main drivers to AM production is its technology itself. The adopters have given credits on the usefulness of the technology, they stated that with the AM technology it has made their production process very easy, and they were able to reduce the bottle necks. The adopters also discussed a positive note on the precision and accuracy of AM technology. All their statements seem to have credited the findings from the previous research. Regarding the supply chains, previous research has discussed to lower the production and inventory steps and could shorten and improve the value chain (Marak, et al., 2019; Ukobitz, 2021). These statements were also discussed by the companies that participated in the research. Cohen, (2014), Mohsen, (2017) and Mani, et al., (2014) benefited the ease of use and mass customization of AM, the ease of use of AM was discussed by most of the adopters of AM technology. The reduction of environmental impact was discussed by Schniederjans & Yalcin (2018) and also discussed by the adopters of AM technology.

It was stated earlier that the technological factors are the main drivers for technology adoption, however there are a few barriers in the technology as well, the three barriers which are related to technology factors are cost of AM machine, technological maturity, and material maturity. The highest factor among the technological factor was the cost. The literatures state that the initial costs are relatively high (Schniederjans & Yalcin, 2018; Dwivedi, et al., 2016), however some of the respondents stated that the printers have become affordable right now, however it is still a barrier as most of the non-adopters have not adopted because of the cost of AM machines. The AM standardization was also called as a barrier as the companies mentioned that there are high number of printers available making the decision process difficult and there is no uniform standard of AM technology. Gao et al. (2015) research supported by adding that there are variety of machines and materials available making it challenging to have uniform standard in AM technology. The next barrier related to technology is material maturity, the companies have illustrated their drawbacks stating the ability of printing only one material at a time and Mellor et al. (2013) adds that most of the AM technologies have the capabilities of processing only one material and a time and the less availability of materials for printing was pointed out as another barrier (Schniederjans & Yalcin, 2018)

The results from both drivers and barriers show that the main attributes for AM adoption is the technology, this factor was measured in TOE framework. The advantages of AM technology weigh more than its barriers making AM to be adopted further by the non-adopters. The benefit of AM technology is its technology itself, however the environmental and organizational factors play a major role in technology adoption as well. All the three characteristics need to be favorable for successful organization adoption.

7 Conclusion

This section includes the conclusion of the research. It also includes the limitations and the recommendations for future research.

7.1 General overview of the research

The purpose of the research was to cover the aspects that have not been well-explored in this field. This research intended to study the organizational characteristics of both adopters and non-adopters of AM technology and further compare the characteristics. The results of the characteristics of adopters should provide insights on preparing firms for technology adoption. The characteristics that were discussed in this study were organizational, environmental, and technological characteristics.

To implement this research, the data collection was taken through conducting semi-structured interviews. The data collection resulted in 9 interviews, which consisted of 4 adopters and 5 non-adopters. The findings were broken down to codes and analyzed through thematic analysis. The thematic analysis resulted in three major themes, they are organizational characteristics, technology factors and finally environmental characteristics. To further back my research, Technology-Organizational-Environment (TOE) framework was implemented. The result of TOE framework was that considering the technological and environmental factors the drivers were more than the barriers in terms of the adopters. The result of TOE frameworks for non-adopters resulted in more barriers to adopt, showing that the non-adopters are still hesitant to adopt to AM technology due to several factors as stated in the framework.

Finally, the research question was answered based on the findings and theoretical frameworks, the characteristics contributing to organizational adoption were compared with adopters and non-adopters and the same was implemented to environmental characteristics and technological characteristics. The result showed that there is a great willingness and experience among adopters which could influence the adoption behaviour among non-adopters. Furthermore, there are no implications on size, age and location of firms and finally the adopters stated that there will be a requirement for skilled workforce and restructuring to ensure smooth workflow. These points can be useful for the new adopters of AM technology. The result of environmental characteristics resulted in stating that the environmental factors are crucial to adoption of AM technology, when there is raise in any of those factors there could be a raise in AM adoption. Finally, the technological characteristics are the most crucial factors to technological adoption. Most of the characteristics pertaining to limiting or influencing technology adoption were technological factors followed by the external factors of AM adoption. Although the technological factors were listed the most important, the adoption of AM technology will not exist without the environmental and organizational factors. Therefore, technology, environment and organizational factors are crucial for successful organizational adoption of the technology.

7.2 Limitations

On pertaining to the existence on existing literatures on organizational characteristics of AM technology, there were very less relevant research in this field. Gathering the literature for the organizational characteristics was difficult.

Coming to the methodology section, some of the research participants had to rush the interviews a bit as they did not have enough time. Language barrier was a major constraint in this research. At least two of the potential research participants denied the request as they do not speak English. In one interview there resulted in miscommunications at times as he/she was not fluent in English. The next is the time constrains, most of the contacted professionals pushed the interviews to later dates which was not suitable for this research. Some of the respondents cancelled their interviews in the last minute due to some urgent matters. Additionally, most of the research participants who were narrowed down in the sample size where not able to participate in the interviews due to the lack of time, therefore all the potential research participants were contacted from the data of 71 dental technology companies who have agreed initially for interviews, out of which 9 research participants agreed for interviews. Due to this, the variation in data couldn't be achieved, the initial plan for sampling criteria was to vary the firms with aspects to number of employees, location of the firm and age of the companies. However, there were some variations in the final data collected.

As discussed in the findings section with respect to size, age, and location of the firm there is not enough data to validate from the respondents. For example, there is only one respondent who mentions location as a barrier. There were no respondents mentioning age of the firm on the adoption context. Talking about the size of the company, they relate back to the economical statement rather than the capacity of the organization. All the dental technology companies within the sample size were listed as small companies and this could not be compared with the case of big companies. Organizational characteristics is not dealt deeply in research yet, a quantitative approach with larger sample population could have yielded a better result on the comparisons. Some of the factors considered could not be backed up because of less evidence.

Finally, the mode of interviews. This is just a minor limitation; the mode of the interviews was through Zoom. Having face to face interviews, could have generated more information from the respondents, as the dental technical labs can be visited, and the organization and layout could be observed. Participant observation could have resulted in more insights on the organizational characteristics.

7.3 Further research

Regarding the age of the companies, the data compiled generated in finding that the new firms are more likely to adopt AM, which is a direct contradicting statement to the hypothesis of Ukobitz (2021), however conclusions couldn't be generated as there was less amount of data. The hypothesis stated by Ukobitz (2021) was 'The incumbent firms are more likely to adopt AM when compared to the newer firms. This statement can be a future hypothesis for testing but cannot be validated in this research as the sample size is relatively small. Two hypotheses can be tested "Incumbent firms are more likely to adopt to AM technology than the newer companies" or "The newer firms are more likely to adopt to AM technology than the older firms"

The next possible research could be to stick specifically to the size, age, location, and origin of firms. This can be evaluated by quantitative research. The origin of the firm is based on how the firm was created such as 'subsidy of a larger firm', 'owned by a private firm', 'owned by the government' and so on. This could deal with in-depth characteristics of the organization.

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Appendix

Appendix A - Interview Guide for adopters of AM Technology

QUESTION SET -1: ADOPTERS	
S.NO	**QUESTION**
1	What is your professional role in the firm?
2	How many years have you worked in this field?
3	What is your level of education?
4	Could you please tell me in detail about your firm and your operations?
5	What do you know about additive manufacturing technology?
6	How do you perceive AM technology in your industry?
7	How can AM be used in dentistry?
8	What are the benefits of AM in dentistry?
9	Does your firm use AM technology in any way? In what way?
10	Why did you start using AM technology?
11	How many years of experience does your firm have in AM technology?
12	Do you use AM in your products or production?
13	Do you print your components by yourself? If not, who prints them?
14	When did your firm start using AM technology?
15	Did possibilities to increase your competitive position in the market influence your choice to start using AM? In what way?
16	Did consumer preferences influence your choice to start using AM technology? In what way?
17	Who made the decision to incorporate AM to your operations?
18	Did you face any challenges when starting to use technology? What challenges?
19	Are there any existing challenges concerning your use of AM technology? What challenges?
20	What are your future plans concerning AM technology? Are you planning to expand your use of AM? How and what?
21	Do you get request from external organizations for customized products?
22	What type of requests do you get? Is AM part of that?
23	Is there any advice that you would give to future adopters of AM technology?
24	Were there any economic factors on investing on AM technology considered as a challenge?

Appendix B - Interview Guide for non-adopters of AM Technology

QUESTION SET -2: NON ADOPTERS	
S.NO	**QUESTION**
1	What is your professional role in the firm?
2	How many years have you worked in this field?
3	What is your level of education?
4	Could you please tell me in detail about your firm and your operations?
5	What do you know about additive manufacturing technology?
6	How do you perceive AM technology in your industry?
7	Is there any reason for not using AM technology? What in that case?
8	What would be needed for you to start using AM technology?
9	Have you ever received requests for producing customized products from external organizations?
10	What type of requests and what production methods do you use for it?
11	Is there any plan to incorporate AM technology in future? In what way?
12	Do you see any challenges that might arise by incorporating AM technology in your operations? What challenges?
13	Could you please list the most important reasons that might influence your decision to start using AM technology?
14	Do consumer preferences in the market affect your decision towards AM?
15	Do possibilities to increase your competitive position in the market affect your decision towards AM?
16	If you start getting requests for patient specific products that you might need to use AM technology for, will you invest in AM technology or rather outsource it? Why?