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# Dental health care technologies:

## factors affecting technology adoption and latest information technology solutions

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**Abstract**

The thesis studies the factors affecting information technology adoption in dental health care. The scope is on information systems used in diagnostics and clinical work. Besides the factors affecting technology adoption, the possibilities and challenges of two important technologies, 3D virtual workflow and CAD/CAM are introduced. The 3D technologies are studied further through a case study, Planmeca Romexis 3D applications. Through the thesis, the effects of the technologies for the whole value chain from the technology vendor to the patient are evaluated. Also, the economical side of the technologies is discussed.

The thesis is based on a broad literature review. At first, dental clinical workflow is introduced to understand what kind of environment the information systems are facing. Second, a theoretical framework for technology adoption including Technology Acceptance Model by Davis (1989) and related theories is constructed, followed by a more throughout literature review on the factors characteristic to clinical environment and dental health care. The literature review is supported with the case study and interviews of specialists.

The literature review finds various factors for technology adoption in dental health care. These factors are divided into usability and functional factors, work efficiency factors, learning curve factors and social & organisational factors. The general theoretical framework can be seen rather applicable for dental health care scope, but some factors such as patient safety or dental team's sociocultural relationships are very characteristic to dentistry.

3D virtual workflow and CAD/CAM are seen to provide advantages into dentistry, and they're bringing solutions to the factors discussed in the thesis. The thesis founds also challenges and problems arising from these technologies. Planmeca's solutions are providing further insight on the possibilities of real-life solutions for 3D virtual workflow.

The thesis has limitations since it's based on a literature review, but a similar Information System Management-view for information systems in dentistry is rather rare. Thus, it can provide information on which factors to take into consideration for vendors designing dental information systems as well as for organizations that are considering investing in new information systems.

**Keywords** technology adoption, dental health care, information systems

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### Terminology related to dental health care

CAD/CAM = computer aided design and computer aided manufacturing. Used in dentistry to design and manufacture for example tooth prostheses.

Cephalometry = measurement of the skull and head, used especially in radiographic imaging.

Orthodontics = a branch of dentistry specializing in treating patients with improper positioning of teeth when the mouth is closed, which results in an improper bite.

Orthognathic surgery = corrective jaw surgery.

Occlusion = bite; The alignment of the teeth when the mouth is closed

# 1 Introduction

Information systems are used widely and with a great success in different areas of health care. The term of health information technology (HIT) covers a huge, diverse set of technologies used for health care, used by clinics, patients and all the other linked groups such as authorities. A large part of these technologies is used for managing information: electronic health records (EHR), personal health records (PHR) and clinical data exchanges are in wide use in all fields of health care (Blumenthal & Glaser 2007). In dental health care, the adoption of information systems is lacking behind compared to general health care (Schleyer et al. 2011).

That doesn't mean that the possibilities of the information technologies haven't been acknowledged in dentistry. There's a consensus between the researchers that IT will improve dental clinical work drastically, according to the survey of Goh et al. (2016). As the technologies are already widely used for data recording, administrative tasks and logistics, the potential is seen especially in the diagnostics and clinical work (Van der Zande et al. 2013).

In dentistry, the technologies rarely bring anything radically new – they replace an analogue method or a current inefficient technology. They cannot replace the expertise of a dentist, but they can be used to improve the daily work and efficiency of an individual as well as the collaboration of the whole team. Dental specialists are expensive workers to be used for manual tasks or to be waiting around because of outdated, slow information systems. That's one of the reasons why it's important to recognize the factors affecting information technology adoption in dental clinic environment. Another obvious reason is that with the help of new information systems, the level of treatment could be improved. The existing literature finds factors affecting information technology adoption widely for general health care, but in a dental health care scope, the research has focused on technical and medical details. An information systems management-view on technologies in dental health care is rare, giving motivation for this thesis.

In order to understand the factors affecting technology adoption, it's crucial to understand the opportunities of modern information technology applications in dentistry. This thesis introduces the most important technologies disrupting the field right now. The dental health care exhibition in Helsinki (November 2017), which I visited, gave good insight about what's on the surface in the industry now. Information technologies - especially 3D imaging and CAD/CAM technologies – were strongly presented, and thus they've been chosen for further discussion in this thesis. Working in Plandent Oy, a subsidiary of a dental health care technology company Planmeca Oy, acts as another source for motivation to study the subject. Planmeca Oy is also included in this thesis as a case study.

## 1.1 Research questions and objectives

The key research question is to find the factors affecting information technology adoption and acceptance in dental health care. Besides the factors, the effects of the technologies on the working efficiency are studied. Thus, the second research question of the thesis is: what are the most important technologies disrupting the dental health care right now? As described more accurately in Scope of the Research, the research questions cover technologies for diagnostics and treatment. The effects of the technologies for the whole value chain, from the technology vendor to the patient, are evaluated.

The first objective of the thesis is to find out how the existing literature and research cover the research question about the factors affecting technology adoption. Second, the thesis reviews how well the new technologies are measuring up to the findings from the literature. In other words, the objective is to study the opportunities of the most important technologies closer. The research questions are brought into practice with a brief case study of the software applications provided by Planmeca Oy.

## 1.2 Scope of research

The research questions of the thesis are approached with a focus on information systems management: technology adoption, factors for technology acceptance and financial effects are studied. In this thesis, the point of interest is not in the information management technologies, (different variations of patient data records). Systems for administration, communication and financial planning in the clinic aren't dealt with either. The thesis will focus on information systems used in the clinic to improve the diagnostics and decision making of a dentist or a dental specialist. The technological side is presented on a broad level, in order to understand the possibilities of the technologies introduced. The objective of the thesis, though, is not to describe technological details. The same applies with the diagnostics and medical questions: medical details are included in this thesis only to the extent needed for understanding the characteristics of dental health care.

The effects of technologies are evaluated through the whole value chain from the vendor to the patient. Where should the vendors focus when developing new technologies? What are the factors affecting organizations that provide dental health care? How is the work of a dentist affected, and how are the technologies making the dental health care better from the view of the patient, who is the customer in dentistry? The focus is still on the clinical work and the work of an individual dentist. The thesis has also an economic view on the technologies.

In the technology introduction part, the scope is to find the most disrupting and influential new technologies. The thesis tries not to introduce all the information systems used in dentistry, but to examine the technologies that have already changed dentistry and are most likely to change the field in the near future. Applications of the 3D technologies provided by Planmeca Oy are introduced to extend the view of existing literature and to give insight what real-life opportunities the technologies are giving.

## 1.3 Structure of the thesis

The structure of the thesis is constructed to run from theory towards practice and from general towards a more specific view. First, in chapter 2.1, the dental workflow is described briefly in order to understand the environment the information technologies are facing. Next, chapter 2.2 creates a theoretical background for technology adoption and acceptance in general. The chapter combines three parallel theories in order to create a solid framework. The following chapters (3.1-3.4) describe the factors characteristic to clinical environment and especially dental health care. The factors are divided in four chapters – the usability and functional factors, work efficiency factors, learning curve factors and social & organizational factors. This division is solely for structural purposes and is only loosely based on the theoretical framework. After the factors have been discussed, the information systems' vendor's point of view is studied with an analysis of the IT system design in chapter 3.5. IT system design is reviewed through the characteristics of the dental health care from the previous chapters.

Next, the most important technologies disrupting the dentistry are introduced. In chapter 4.1, a 3D virtual workflow is introduced. The virtual workflow is divided as follows: at first, the acquisition of the information with 3D imaging is handled. Second, digital image analysis is discussed: how a 3D model is created and how it can be analysed with different techniques. That is followed by the virtual treatment planning and treatment evaluation enabled by the 3D technologies. In the next chapter (4.2), the real-life case of Planmeca Oy's software solution, Planmeca Romexis, is introduced. The Romexis platform covers a wide set of applications, but the thesis focuses on the 3D applications provided in the software. At last in chapter 4.3 another important technology, CAD/CAM (computer aided design and manufacturing) is discussed. CAD/CAM review consists of three parts: creating the model, computer aided designing and computer aided manufacturing. By combining the technologies introduced, the complete virtual workflow of modern dentistry is analysed. The discussion and conclusion part reviews the overall findings of the thesis and how the technologies are measuring up against the findings in the literature.

## 1.4 Methodology

The thesis is based on a broad literature review on the subject. The theoretical background used for the literature review was chosen with two criteria: the level of appreciation towards the theories in information systems science and the suitability for a dental health care scope. For technology adoption factors in clinical environment, articles dealing with general health care and more specifically dental health care were searched. The topics for further discussion about the technologies are mainly found in rather specific journals in the field of dentistry, so the reference database Scopus is used for verifying the relevance of the sources. Google Scholar was also used to acquire information not provided in Scopus. The articles citing the most important sources were reviewed and used, if they included more accurate information.

The sources used for this paper are mainly scientific articles, supported with the latest reviews and surveys. The relevance of the sources is based on article metrics provided by Scopus, amount of citations and the evaluation of the publication or publishing institution. Due to the quickly changing nature of the topic, the year of publication was an important criterion when choosing the articles for the literature review. The topicality was emphasized when studying the latest technologies in dentistry.

The literature review is supported with an interview of Planmeca's technical product specialist, Anna Vottonen (3.12.2017) and an interview of a Finnish dental specialist, which was conducted anonymously (13.12.2017). The case study, Planmeca Romexis is based on technical information provided by Planmeca Oy and on Vottonen's interview.

# 2 Background

## 2.1 Dental workflow and information systems

Dental workflow can be described as complex. When excluding the most common, routine control appointments, the work of a dentist, and especially a dental specialist includes a vast number of variables, and rarely is the treatment of the patient done exactly same as in some other case. The decision making in dental health care is everything else but linear (Irwin et al. 2009). The following chapter discusses the factors that might be affecting the decision making of a dentist in the daily work.

The work of a dentist is affected by the condition of the patient, available machines, materials and drugs, whether the materials and drugs can be used for the exact patient, and the desired outcome. The patient might also have the role of decision-maker: he/she might have aesthetical or economical demands on the treatment. The work of a dentist is also often team-based: The dentist works with dental nurses, hygienists, radiologists and other professionals, who all might have opinions and views on the treatment. All these variables are affecting the decision making inside the treatment room, but also external variables exist. The decisions made for the treatment are affected by the time constraints, organization culture, economic issues, protocols used in the dentistry and even legal issues. (Goh et al. 2016, Song et al. 2010)

In this framework, it is evident that information systems, that are supposed to support the decision making in the daily work, are required a lot. The workflow is difficult to standardize and thus difficult to computerize. Still, many information technologies have been introduced to help the improve decision making of a dentist and to help the workflow to become more efficient.

## 2.2 Factors affecting technology adoption: theoretical background

In 1989, Davis introduced the Technology Acceptance Model (TAM) as a universal framework for technology acceptance. The model includes only three factors affecting technology acceptance: behavioural intention to use IT, perceived usefulness of technology and perceived ease of use, two last ones belonging into “attitude towards technology”. According to Yarbrough et al. (2007), TAM is widely recognized in the information systems literature and it’s an applicable base for analysing technology adoption in health care. Evolving from the original TAM, Venkatesh et al. (2003) created the Unified Theory of Acceptance and Use of Technology (UTAUT) by combining eight former theories. The theory consists of four determinants affecting the user acceptance of technologies: performance expectancy, effort expectancy, social influence and facilitating conditions.

In the UTAUT model, Performance expectancy consists of relative advantage of the technology, outcome expectations and job-fit – it answers the question how is the new technology going to affect the job efficiency and productivity. The effort expectancy defines the ease of use of the technology. Complexity, interaction with the system, learning to operate the system and perceived ease of use are recognized as factors that affect the acceptance of technologies. Social influence is measuring the degree of how much influential people are affecting the acceptance of technologies. Management and the attitudes in an organization are seen as sources for social influence, affecting the norms and image of the person who is considering applying new technologies. Facilitating conditions are defined as the degree of individual's belief of organizational and technical support for the use of a system. The level of control over a new system, relevant resources, combability with other systems in an organization and available support and assistance are suggested to affect the willingness to adopt new technologies.

As another comprehensive, widely accepted theory for technology acceptance, DeLone and McLean introduced the Model of Information Systems Success in 1992 and updated it in 2003. The updated model includes six factors affecting technology success: system and information quality, information systems use, user satisfaction, individual impact and organization impact. TAM, the Model of Information Systems Success and related theories such as UTAUT are seen to be generally acceptable in health care (Holden et al. 2010, Pai & Huang 2011). Even though the suitability of TAM related theories in health care are studied widely, Holden et al. state that the TAM models cannot be implemented straight into clinical practise as a comprehensive theory, which is due to the essential characteristics of clinical environment (Wu et al. 2007). Whether a complete TAM for health care can and will be constructed remain unclear (Holden et al.), thus the characteristics of clinical environment and more specifically dental clinic characteristics are now studied further in chapters 3.1-3.5.

# 3 Factors affecting technology adoption: dental clinic environment

## 3.1 Usability and functional factors

Information quality is reckoned as a major factor for general technology success by DeLone and McLean (2003). A great advantage of the IT systems in clinical use is the accuracy of information: they should help the dentist to make faster, better informed and more accurate decisions, as will be noticed especially in the chapter covering digital image analysis. In decision making, IT technologies can avoid problems caused by variations in a manual worker. A sophisticated IT system can make a diagnosis for a similar problem for endless times in a row and it doesn't get tired, bored or angry. The decisions made by an algorithm are always objective and not affected by personal preferences or the relationships between the doctor, patient and the dental team. (Wang et al. 2016) According to Gagnon et al. (2012), validity of information is a major factor for technology adoption. In a clinical environment, misdiagnosis and malpractice might lead to expensive compensations and legal suits (Goh et al. 2016, Gagnon et al), thus the consistency and accuracy of the information is a key factor in technology adoption in dental health care.

The functionalities of the technologies naturally set limits to their usefulness and those limitations can be seen as an obstacle for adopting technologies. A study made by Schleyer et al. (2006) in the US discovered the general dentists' use of information technology. A decade ago the usability problems of the computers in dental clinical use were often technology-orientated and related with reliability, space, speed and user interface. Any similar study from recent years wasn't found for this thesis, but it can be assumed that the general development of technology might have affected the factors presented by Schleyer et al. Yet other usability factors characteristics for dentistry were found; the ease of use is one of the three major factors affecting technology acceptance in the original TAM, and Gagnon et al. (2012) recognize it to apply in the clinical environment as well. Other factors including standardization, system integration, data privacy, patient safety and readiness of the technologies are now discussed further.

In diagnostics, even the most sophisticated information systems require often rather standardized cases before they can be utilized - creating such standardized situations is difficult in the fuzzy workflow discussed above (Devaraj et al. 2014). For example, a digital image analysis algorithm can only process images with standard size, resolution and positioning of the patient. Also, the complexity of a human body and variations between patients creates challenges for the technologies: especially difficult are the situations when the patient has strong malformations in the area of interest. (Yu, 2016) Implementing a new technology often means that the treatment process needs to be redesigned as more straightforward and linear. Redesigning the processes is often difficult and takes time off from the actual clinical work, but as a reward, the workflow will become faster and clearer. Standardizing also reduces variation in the workflow, which will lead into more accurate decisions in the treatment. (Van der Zande et al. 2013)

With a growing number of software in use, the integration of them becomes an issue, just as Venkatesh et al. state in the UTAUT model's facilitating conditions. As many of the technologies in dental health care haven't been in use for long, the systems still lack data standards. The integration problems are emphasized between different vendors and countries (Irwin et al. 2009, Phen Goh et al. 2016). Just like with all information systems, data privacy is a concern in dental health care. Characteristic to health care, the data used in dental information systems includes very personal and thus delicate information about patients' medical conditions (Goh et al.).

Patient safety, as well as the dentist's safety needs to be evaluated when adopting new IT systems. Sterility of the working devices and infection control are characteristic factors for technology adoption in health care. Some operators have raised concerns whether working with computers during the appointment might add infection risks (Irwin et al. 2009). When acquiring information for digital radiology analyses, the radiation doses needs to be controlled and kept as low as possible, making the data acquisition harder (Vottonen 1.12.2017, an interview).

Yarbrough et al. (2007) regard the lack of evidence on whether a new technology actually increases productivity or quality of work as a factor affecting technology adoption in clinics. Van der Zande et al. (2013) have found that new health technologies are often marketed before their full functionalities are evident, thus many dentists want more information on the technologies before making the investments. In the same study some dentists, on the other hand, argue that the technologies are never completely ready - and they should be adopted rather sooner than later, even though the usability isn't perfect and the functionalities could develop in the next couple years, in order to take competitive advantage on the markets.

## 3.2 Work efficiency factors

Just as in the UTAUT model's performance expectancy, the work efficiency provided by information systems is a critical factor in dental information systems' adoption. As discussed in chapter 2.1, the workflow in a dental clinic is hectic. In order to improve working efficiency, information systems are required to provide the information needed quickly and smoothly (Spallek et al. 2010). According to Van der Zande et al. (2013), IT applications can make the working significantly faster. The technologies can improve the treatment times: for example, the implant planning with CAD/CAM technologies might significantly shorten the time needed for the implant design and manufacturing. CAD/CAM technologies are discussed further in chapter 4.3.

Interruptions in the workflow are seen as a major challenge of the technologies. Interruptions arise from crashes of the systems, slow response times, complex user interfaces etc. Slower workflow leads into other problems such as economical disadvantages and patient discomfort due to longer appointment times. (Schleyer et al. 2011) An example from the article by Irwin et al. (2009) shows, that eight years ago taking a digital radiology image might have improved decision making and the diagnostics, but the process included more steps and lead into more breakdowns than a conventional one. The work efficiency of modern digital imaging is evaluated further in chapter 4.1.1.

With the help of information systems, variations in skill and expertise level between dentists can be equalized. Complex tasks can also be transferred from the dentist to other members of the working team. Many tasks in the treatment, such as analysing images, planning the treatment or selecting the right materials for the work, require the expertise of an experienced dentist when performed manually. With information technologies, also dental nurses and hygienists can carry out these jobs accurately. By assigning this kind of work to the rest of the team, the dentist can focus on the patient work – the working gets more efficient and the dentist can communicate better with the patient, as he/she doesn't need to use time on the supportive analysing tasks. (Van der Zande 2013) If the workload of a dentist gets increased due to a new information system, the technology adoption is likely to fail. (Gagnon et al. 2012)

## 3.3 The learning curve factors

The level of familiarity with IT is affecting the willingness to adopt new technologies for clinical use (Yarbrough et al. 2007). New technologies require new expertise, even though the development of the systems should be user-friendly and intuitive. Re-education for the new technologies is often provided by the vendors – user training and support are important factors in clinical technology adoption (Gagnon et al. 2012). Courses for new technologies are often costly, and the dentists might have to travel a lot to get the most current education about the technologies. An example of a dental education institution is the Finnish NIDE (Nordic Institute of Dental Education), a collaboration between Turku University and Planmeca Oy. NIDE provides international courses on current topics such as 3D imaging and CAD/CAM technologies. (www.nordicdented.com)

Getting education demands time, which always reduces the time available for clinical work – according to Gagnon et al. (2012), time constraints are a major barrier for successful technology adoption. Time is also consumed when the dentist is not yet quite familiar with the technology, and the risk for mistakes is higher before the dentist is fully comfortable with the new technology (Van der Zande et al. 2013).IT skills and readiness to work in a digital environment has naturally an effect on technology adoption (Yarbrough et al. 2007). For an experienced dentist, who has worked manually for the whole career and who hasn't studied in a digital environment at all, new technologies can appear to be difficult and unnecessary (Van der Zande et al. 2013). According to Schleyer et al. (2012), the dental education has lately adopted the use of information technologies well, and newly graduating dentists have good readiness for new information technologies.

## 3.4 Social and organizational factors

*"To some of the experts digital technologies are but a small force of change among many others, changing at most the means of providing dental care. Others view the transformations that digital technologies give rise to as profoundly altering the profession, now and in future years." (*Van der Zande et al. 2013)

In the model by Venkatesh et al. (2003) social influence was seen as a major factor for IT acceptance, and DeLone and McLean (2003) talk about individual impact and organization impact. Also in a clinical context, besides technological issues, many sociocultural factors affect the IT adoption. The technologies in a clinical environment are challenged by individual preferences, interactions between the dentist and the patient, between the dental team, and organizational factors (Gagnon et al. 2012). Considering the individual factors, Van der Zande et al. (2013) have recognized that the curve of adoption for technologies (Rogers, 2010 p. 257) can be applied to dentistry. The theory by Rogers divides the intended users of the technologies into 'innovators', 'early adopters', 'early majority' and 'laggards' based on when they're ready to adopt new technologies. In dentistry, the early adopters are often specialists rather than general dentists, and young, recently graduated rather than older dentists (Van der Zande et al. 2013)

Individual preferences and resistance appear often as follows: clinical operators are used to a high level of autonomy in their own work, and they value their expertise. This might cause resistance to the adoption of the IT systems as supportive elements. Doctors might for example be reluctant to use the systems in front of patients – they don't want to be perceived as lacking skills for the diagnosis (Varonen et al. 2008). This might seem like an old-fashioned way of thinking, but in the culture of high expertise and autonomy it can actually appear. Health technology has often faced resistance due to this reason: for example, when blood pressure monitors were first introduced in the early 20$^{th}$ century, doctors thought that it would challenge their unique skill of measuring blood pressure without any devices. Nowadays, the machines are used everywhere. (Crenner, 1998)

According to the survey by Goh et al. (2016) as well as Gagnon et al. (2012), some professionals argue that IT systems might disturb the patient-dentist communication. Patient's attitude towards IT might also affect the willingness to use the technologies (Devaraj et al. 2014). The attitude of colleagues towards IT might affect the willingness to adopt new technologies: adopting new technologies might be seen innovative and influential, or they can be seen as threats for the roles and task distributions inside a dental team. On an organizational level, the organizational support and management attitudes are proposed to be important factors for technology adoption. For example, if the organization allocates only little time for learning new systems, the adoption of technologies gets distracted. (Van der Zande et al. 2013, Gagnon et al. 2012) Similar to the UTAUT model's facilitating conditions, The IT support provided by the organization has an effect on the technology adoption in a clinical environment (Gagnon et al.).

The costs are a further organizational factor affecting technology adoption - the costs are an important issue when deciding which new technologies to choose. Costs of technologies include purchasing, updating and maintaining the systems as well as the learning costs discussed in previous chapter. Also, the cost for breakdowns need to be noted: rework and alternative methods needed during maintenance increase the technology-based costs. (Gagnon et al. 2012, Van der Zande et al. 2013) Dental health care is competitive, and all new technologies need to be evaluated as investments. In private sector, investing can be challenging for small, one- or two-room clinics that have less free capital. Bigger operators and chains can absorb unsuccessful investments better, and thus they have a better ability to take risks with the technologies. A study from the Netherlands (Van der Zande et al. 2015) supports this view: in the study, the bigger the clinic was, the more technologies were used. On the other hand, Vottonen (3.12.2017, an interview) argues that the bigger the clinic is, the more there are bureaucracy and organizational limitations combined with a slowly adapting information management, compared to smaller, specialized clinics – specialized clinics are often the early adopters for the most specialized technologies.

## 3.5 Vendors' view: Design of the systems

Pai and Huang (2011) integrated the TAM and DeLone's and Mclean's Model of Information System Success into health care environment and found the following factors to stand out: making sufficient information available, having good interface design and ensuring on-time updating of information on the system. When reaching for success within these factors, it all comes down to the design of the systems. Schleyer et al. (2011) have found principles to be followed when designing any new information system used for diagnostics and patient work in dental clinic environment. The systems cannot be designed without understanding the workflow and how the information is handled in a clinic environment, and it is critical to understand the protocols of dentists before trying to apply any new piece of IT in use. Trying to create IT solutions for dental healthcare only from technical perspective is doomed to fail, as the technologies are used in a highly complex working environment.

The article by Schleyer et al. (2011) emphasizes the importance of *user-centred design:* all the technology solutions should be designed specifically for the needs of the dental expert, otherwise the technologies will provide no help in the hectic, complex workflow. A lot of collaboration between the technology and dental experts as well as with the vendors is required in the design phase of the technologies. Also Gagnon et al. (2012) noted the participation of end-users in the design to be a major factor for successful clinical IT applications. Even the finest technologies might fail if there's a gap in the fit between the technology and clinical working practices.

Without a well-designed, intuitive and easy to use user interface, the features of the IT systems cannot be fully utilized. The dentist should be able to navigate easily and find the relevant features and information with little trouble, using one (or as few as possible) source for information (Song et al. 2010). This means that the systems need to be simple to use, even though their features might be very complex. Fast response times are also needed, in order to keep the work flowing without breaks (Goh et al. 2016).

# 4 The technologies disrupting the field

The chapters 3.1-3.5 discussed the factors affecting technology adoption and acceptance in dental health care. Next, in section 4 the most important technologies disrupting dentistry are introduced, and their effects, opportunities and challenges in dental health care are evaluated. Subchapter 4.1 focuses on 3-dimensional virtual workflow and 4.2 on Planmeca's 3D applications. Subchapter 4.3 focuses on CAD/CAM technology. The purpose is also to study whether the technologies are giving solutions to the factors discussed in section 3.

## 4.1 The technologies: dental 3d virtual workflow

Three-dimensional imaging and virtual planning have brought a whole new way of working in dentistry. They're used especially in orthognathic surgery (surgery in the jaw area to treat issues that cannot be cured with traditional orthodontics such as braces etc.), implant planning and orthodontics. Swennen et al. (2009) have recognized a full, virtual 3D workflow that can be applied in dentistry. The workflow includes acquisition of the digital image, processing the image into a virtual 3D model, virtual diagnosis and treatment planning, transferring the planning into the operation with the use of 3D designed advising devices, and at last, virtual treatment outcome evaluation. This workflow is now split in three parts and the possibilities and challenges of the different phases are studied.

### 4.1.1 Image acquisition: 3d radiographic imaging

The first phase in 3-dimensional digital workflow is the acquisition of the data by dental radiograph imaging. Dental radiography has a big role in clinical diagnosis, treatment planning and surgery. The radiographic imaging can be categorized into intraoral and extraoral imaging. Extraoral imaging is used to detect problems in the patient's bones, soft tissues and dental structures in the area of jaw and skull. The methods used for extraoral radiography are e.g. cephalometric projections and panoramic X-ray images. Intraoral radiographs, on the other hand, are used to present details of the teeth and soft tissues in the area of the mouth. Intraoral radiographs are taken with small, hand-held intraoral scanners. (Wang et al. 2016)

Dental imaging can be done two- or three-dimensional. 2D is a more conventional way for imaging and is suitable for many basic treatments. For many analysing purposes, e.g. for an advanced cephalometric analysis (skull measurement analysis), 2D doesn't provide enough information. 2-dimensional analysis misses many important parameters and gets distorted when facial asymmetry is present. (Centenero & Hernández-Alfaro

2012, Gateno et al. 2011). On the other hand, van Vlijmen et al. (2010) state that the third dimension brings an additional source for inaccuracies compared to 2D imaging, especially when locating anatomical landmarks from the images. 3D is a rising technology in the field of dentistry and dental surgery. In recent years, an imaging technology called cone beam computerized tomography (CBCT) has enabled capturing digital, three-dimensional dental images with a relatively low radiation dose. With CBCT, the imaging can be done with a high resolution and safely for the patient, radiologist and the dentist (Scarfe et al. 2006). According to Baumgaertel et al. (2009), the data acquired from modern CBCT images is accurate, represents the reality well and can be used as a trustworthy source for digital analysis. After acquiring the image, the image is digitalized. A major problem in digitalizing the image that came up in the interview of a dental specialist (13.12.2017) is the integration between the imaging devices and imaging software: the software applications have often difficulties to acquire data from different imaging devices, as they're set to work with one special device only.

### 4.1.2 3D digital image analysis

The second phase in the digital workflow includes the analysing of the image data. The development of hardware and software has created opportunities to benefit from the 3D imaging in various ways. Traditionally, the radiograph images have been analysed by the dentist manually, but modern computerized technologies use complex algorithms for automatic image analysis (Wang et al. 2016). With the modern dental software, a complete, digital model of the patient's skull, jaw and teeth can be constructed. The 3D model of the patient's skull can be used e.g. to analyse the patient's bone structures in a cephalometric analysis or to analyse occlusion and soft tissues. (Lin & Lo 2015)

Digital image analysis can benefit from artificial intelligence applications. The possibilities of neural networks for radiology image analysis have been known for long. The interest towards machine learning in general medicine has been on the surface from the late 80's, and also in the dentistry the possibilities were recognized already in the early 90's. Even though studies were made already in the 1990's, at that stage only the potential was recognised, and the real, useful applications lay far in the future, waiting for better hardware and algorithms. (Boone et al. 1990, Shepherd and Armstrong 1998) The machine learning can be used in dentistry for example with the applications introduced in the next chapter.

A machine learning algorithm can extract the region of interest (e.g. wisdom tooth) from a digital image, which makes it faster for the dental specialist to get to examine the actual problem from the X-ray image (Amer et al. 2015). According to Jiang et al. (2010), image segmentation plays an important part in diagnosis support, as it helps to recognize the outlines of the tissues and structures from the irrelevant tissues. Segmentation simplifies the further diagnosis significantly. Artificial intelligence can also be used for image enhancement (Jiang et al. 2010). In other words, the dental images can be improved with an algorithm that reduces noise, distinguishes the teeth or tissue the dentist wants to examine closer and extracts it from the picture, and removes all the unwanted objects from the image.

According to Wang et al (2016), the modern image analysis systems save time and manual costs in clinical use. One of the best advantages is avoiding problems caused by variations in a manual observer: these problems include fatigue, stress and variations in skill level. 3D models and diagnosis made with the help of image analysis can be shown for the patient in order to enhance his/her understanding for the treatment. The analysing task can also be delegated from the dentist to other members of the team, saving time from the dentist. Yet according to the benchmarking by Wang et al. (2016), computerized automation of image analysis is not yet free from problems and there's plenty of challenges to solve. They e.g. need manually created datasets for the learning process, as the algorithms often use so called supervised learning, so they're not capable of doing fully autonomic decisions. The review by Lin and Lo (2015) finds similar results: 3D modelling and image analysis aren't 100% accurate and the outcomes are yet recommended to be supervised. According to Jiang et al. (2010), the lack of sufficient patient data and sensitivity to imaging conditions are further problems for the effective use of the applications.

### 4.1.3 3D treatment planning and evaluation

The next phase in a digital clinic workflow is treatment planning. With the guidance of the digital image analyses and digitally improved models combined with conventional planning methods, the upcoming treatment can be planned and the results of the treatment can be predicted. Hsu et al. (2013) acknowledged that computer-aided treatment planning provides excellent accuracy and is rather easily reproduced by specialists with different skill levels. For example, a planning software can be used in orthognathic surgery. With the help of a 3D model of the skull, the surgeon can perform virtual, simulated surgery for planning purposes. The virtual surgery gives more information and understanding on the actual surgery, and the results can be predicted before the actual operation. Simulated planning improves the accuracy of the surgery, which enhances the treatment results and the patient satisfaction. (Lin & Lo 2015)

At last, the treatment put into practise needs to be evaluated. According to Plooij et al. (2011), the 3-dimensional virtual models enable great advantages also for postoperative treatment evaluation. Soft tissue changes and jaw movement changes can be studied virtually by comparing the old and new models, and that enables the dentist to measure both functional and aesthetic results. The chapters 4.1.1-4.1.3 have now introduced the whole 3D digital workflow from the imaging to the post-treatment evaluation. Next, Real-life applications for 3D virtual workflow are introduced in the case study of Planmeca Romexis.

## 4.2 Case study: Planmeca Romexis 3D applications

The case company, Planmeca Oy (parent company for Planmeca Group) is a dental health care technology company based in Helsinki, Finland. With 2700 employees, it's the largest privately held dental equipment company. The product range covers dental units, 2D and 3D imaging devices, CAD/CAM technologies and software solutions. (Planmeca.com) This part of the thesis will cover a case study over Planmeca's software solution, Planmeca Romexis.

Planmeca Romexis is a medical imaging software intended for use in dental health care as a tool to displaying, visualizing, analysing and diagnosing 2D and 3D images from different imaging devices. It is also an application for preoperative treatment planning in dental implantology. It also provides tools for recording and analysing jaw positions with a cephalometric analysis. Planmeca Romexis consists of different modules, each one intended for different purpose. According to Vottonen, the 2D applications are used a lot in general dentistry and standard treatments, and the 3D applications for specialized cases that require more accurate information: the 3D images can be used e.g. to find tumours in the head area. Vottonen emphasizes that the 3D virtual diagnosis is especially useful for preoperative planning and reviewing the results of jaw surgery with a "before and after"-analysis. Occlusion design, aesthetic planning and airway measurement are also treatment phases possible to be done effectively only with the Romexis 3D planning modules.

The 3D modules of Romexis include:

**Intelligent tooth segmentation**

In the literature review, segmentation was noted to be an effective way to improve diagnostics. The Romexis' Intelligent Tooth Segmentation module enables to visualize the crown of the tooth or the root canal for more accurate diagnosis n orthodontics, as the tooth movement can be easily simulated. It also improves implant planning by enabling the visualisation of neighbouring crowns and roots. The software provides visually clear presentation of the issue.

**Superimpose CBCT**

One of the most important phases in the 3D virtual workflow is treatment evaluation, but effective solutions for treatment evaluation weren't introduced in the literature review. Planmeca's solution is Superimpose CBCT module, that enables to superimpose images taken before and after the treatment. With the comparison, the results of an orthognathic surgery as well as the results of an orthodontic treatment can be measured.

### 3D rendering view

The Romexis 3D rendering view helps the dentist to visualize the anatomy of the patient, which makes it easy to educate the patient on the diagnosis and treatment. Nerve canal tracing, airway measuring and sinus volume visualisation help to make the diagnosis safely. (Vottonen 2017)

### Romexis ProFace

ProFace can be used for comparing the anatomy of the face of the patient before and after treatment. The module can combine the face of the patient with the bone structures beneath. The software automatically superimposes the images for comparison. By combining the face of the patient in the analysis, the results of a surgery can also be aesthetically designed.

### Implant planning

Planmeca provides a tool for implant planning. The implant planning module exploits the 3D model for planning an implant and placing it safely and stably. With the module, the dentist can verify the implant placement and take the soft tissues of the patient in consideration. The implant planning module can also be used for designing implant guides (small devices used in the operation to guide the placing of the implant). The guide can be printed with a 3D printer and then be used to transfer the virtual plan into reality for a secure and accurate implant placement.

### 3D Ortho Studio: Treatment planning and follow-ups in 3D

Romexis 3D Ortho Studio is a set of tools for planning orthodontic treatment. The software uses a digitalized model to analyse occlusion, tooth movement and anatomy. The treatment can be visualised to see the effects of the planned changes in the tooth position. After the treatment has been performed, the progress can be evaluated with the help of the Ortho Studio module.

## 4.3 The technologies: CAD/CAM

Dental CAD/CAM (Computer-aided design/manufacturing) is a concept used for designing and manufacturing individual dental restorations such as crowns, bridges and partial denture frameworks for prosthodontics (Van Noort 2012). CAD/CAM can also be used for designing surgery assisting devices such as surgical guide templates (a small device used to hold the patient´s tissues on the right place during a surgery) (Centenero & Hernández-Alfaro 2012). The concept of CAD/CAM for prosthodontics was introduced already in the 80's (Ting-Shu and Jian 2015, Miyazaki et al. 2009). During the recent years CAD/CAM has taken huge steps, thanks to developments both in the dental imaging hardware and the designing software. CAD/CAM process can roughly be divided into three phases: creating a model, designing the restoration/surgical device and manufacturing. The recent research has shown that the method isn't yet perfectly accurate, but it provides a great option for conventional prosthodontics and is seen to completely replace the conventional methods in the near future. CAD/CAM manufacturing is faster, cheaper, more reliable and predictable, but one problem lies in the materials which need to be developed further for CAD/CAM purposes. (Centenero & Hernández-Alfaro 2012, Van Noort 2012, Ting-Shu & Jian 2015) According to Miyazaki et al. (2009), the amount of labour hours can be reduced with CAD/CAM solutions.

### 4.3.1 Creating the model

Conventionally, creating a model for a prosthesis required taking a physical impression (which is very uncomfortable for the patient), pouring a model - and then measuring it with a mechanical articulator device. The physical model is then possible to digitalize with a laser scanner. One of the most important developments in dental CAD/CAM has been the introduction of effective intraoral scanners. With an intraoral scanner, a digital 3D model of the oral cavity can be created quickly and easily. (Solaberrieta et al. 2015, Van Noort 2012)

Compared to the conventional method of taking impressions for the model, Ting-Shu and Jian (2015) recognise 11 steps that can be eliminated with intraoral scanning (e.g. material setting, material disinfection, extraoral scanning). That means the operation time is significantly reduced – and the level of difficulty becomes lower. Materials are also saved, leading to cost reductions. In case of a mistake, a rescan with an intraoral scanner is quick to take, whereas in the conventional method the whole process needed to be retaken. In addition, in the conventional method the cooperation with the patient plays a big role and adds a lot of uncertainty and risk for error in the designing process. The intraoral scanner on the other hand adds patient comfort and satisfaction through a quick and easy process. (Centenero & Hernández-Alfaro 2012)

The study done by Seelbach et al. (2012) compared three commercial digital impression systems and found them to be as accurate as conventional techniques. According to Van Noort (2012), the scanners are getting faster and more accurate all the time. Multiple studies made by Ting-Shu & Jian (2015) as well as Joda and Brägger (2016) suggest that the accuracy of a digital impression is at least as high as a conventional one. The repeatability and stability is according to Ting-Shu and Jian on a satisfactory level, although improvement on that is still needed. "Distinct superiority" in the work efficiency is evident, and the wide adoption of intraoral scanning will come with the further development of the technology. The digital impression process is preferred by the patients compared to conventional techniques, when assessing patients' perception and satisfaction - the treatment comfort of digital impressions is superior. (Joda & Brägger 2016)

### 4.3.2 Computer Aided Design

Traditionally the prostheses or other dental devices that can now be created with CAD/CAM were designed with physical plaster models. In computerized design, the restoration can be designed automatically, tailor-made for each patient according to the model – and only one source of information, the digital model, is needed. With 3D models, the planning can be done as close to reality as possible. An important development for the designing software from the recent years is that the CAD/CAM technologies have turned from closed to open access systems, enabling acquiring data flexibly from multiple sources. The systems aren't limited to use the data from a specific source, hence multiple imaging technologies or online sources of images can be used if needed. The data can now also be sent immediately to anywhere it's needed. (Centenero & Hernández-Alfaro 2012, Van Noort 2012) As the data used for the design can be saved, quality control during the use of the restoration is easy to execute. (Miyazaki et al. 2009)

### 4.3.3 Computer Aided Manufacturing

After designing the model, the restoration needs to be manufactured. The data from the model can either be sent to another dental laboratory - by centralizing the manufacturing, economic advantages can be achieved. On the other hand, the manufacturing devices, dental mills, have developed into such small units that they can also be implemented at any clinic. That enables the restorations to be created and inserted immediately. The most common way to produce the dental restorations is subtractive manufacturing: a block of material is put into a computer controlled machine, which then automatically cuts the piece into the desired form. This manufacturing technique enables creating such complex models which are very difficult or even impossible to create with conventional methods. Besides that, a significant amount of time is saved. (Centenero & Hernández-Alfaro 2012, Miyazaki et al. 2009) A major disadvantage of the technology is the waste of materials: when cutting the block, a lot of (often expensive) materials are getting wasted. Another drawback is that only one block can be worked on at a time (Centenero & Hernández-Alfaro 2012). As an alternative, a technology called additive manufacturing has been introduced. With additive manufacturing (a form of 3D printing), even more complex models can be created, with no waste and faster than with subtractive manufacturing. The huge potential of the technology is recognized, yet applications in commercial use are still rather rare. (Van Noort 2012)

# 5 Discussion and conclusions

The first research objective was to find the factors affecting information technology adoption in dental health care. The theoretical background was created using the Technology Acceptance Model (Davies 1989), UTAUT (Unified Theory of Acceptance and Use of Technology) by Venkatesh et al. (2003) and the Model of Information Systems Success (DeLone and McLean 2003). As no single comprehensive theory for technology adoption in dentistry was found, combining three separate but related theories for the framework was reasonable. After reviewing the factors characteristic to clinical environment and dental health care, the framework can be seen rather suitable for the dental health care scope, as most of the factors fit in the framework. Some factors found were very dependent on the clinical environment. These factors include human body variations, patient safety, patient-dentist communication and the sociocultural factors inside a dental team.

The importance of the factors is difficult to rate without further studying, but the factors can be summarized: the usability and functionalities of the technologies need to be sufficient. They need to provide improvement in the efficiency of the workflow, without tying too many resources such as in case of necessary re-education. My view on re-education is though that the learning curve and further education shouldn't be seen as an obstacle for adopting IT, but as a challenge that can be overcome. The dentistry-specified literature emphasized the importance of information accuracy: misinformation would lead to wrong diagnoses, and it can't be tolerated. On the sociocultural side, the individual attitudes, personal preferences and the relationships between the dentist and the patient as well as inside a dental team need to be taken into consideration. Organizational and management support have also a great impact on information technology adoption. Besides all these factors, cost-efficiency needs to be considered when deciding whether to implement new technologies in clinical practise.

When a vendor is designing a system, it has to remember the factors discussed, but also the fact that the dentists often aren't interested in technological details – they value good functionalities and ease of use.  An organization evaluates how is the work efficiency of a dentist improved, and the dentist has to remember the patient's point of view. Thus, the whole value chain from the vendor to the patient is affecting the technology adoption. Patient is the customer in dental health care, and the existing literature sees patient satisfaction as an important factor for acquiring economic advantages from the technologies. If a new technology isn't improving working efficiency or patient satisfaction, there's few arguments why it should be implemented. Yet surprisingly, the dental specialist interviewed (13.12.2017) gave little value for patient's experience on the technologies.

The review of the two significant technological trends, 3D virtual workflow and CAD/CAM, found that the technologies provide real advantages in relation to the factors discussed. The 3D virtual workflow can be performed safely, it can improve the accuracy of information and hence improve the diagnostics. The treatment planning and evaluation enable more accurate decision making for the dentist, which leads into better patient satisfaction through improved treatment outcomes. Planmeca Romexis 3D applications were introduced, and they can be seen to bring to dental health care similar advantages that were found in the existing research. The applications enable more efficient image analysis, treatment planning and treatment evaluation. CAD/CAM technologies are seen to improve the patient comfort, process times and accuracy drastically compared to a manual workflow.

## 5.1 Limitations and future research

This thesis has limitations, both with the literature review and the case company. The literature review is limited by the databases available; they do not include all the most recent studies in the field of dentistry. The review isn't limited to one country or culture, but studies made either in northern or western Europe or in the United States were emphasized. New technologies are rather universal, but the results for the research question about the technology acceptance factors could get significantly different findings e.g. in African or Asian context. The cultural differences in dental technology adoption require further studying. The differences between public operators, private clinics and larger, private chains were only narrowly discussed.

This thesis isn't done as an assignment for the case company Planmeca, but I'm not completely independent from the company, as I have a part-time position in Plandent Oy, a subsidiary for Planmeca Oy. The work in the company might have limited the scope for the studied technologies, and no other companies are studied separately in the thesis. The interviews included in this thesis were unstructured, and there should be more of them to get a more comprehensive image of how the technologies are viewed by dental professionals.

As a suggestion for future research, the factors affecting technology adoption in dental health care should be studied with a wide questionnaire not limited geographically. In the future research, the differences of public and private clinics should be identified, in order to find suitable methods to consider technology adoption for operators with different characteristics. I would also suggest a further study on the patient's role for information systems adoption. Existing literature noted the patient's role, but the interview of a dental specialist gave an impression that in dentistry, the patient is viewed as an object of the treatment rather than a customer, to whom information systems could create value.

The technological research on 3D virtual workflow and CAD/CAM will most likely to continue strong, but the future research should also consider more the economical side of the information technologies. The technologies should be evaluated in future research based on how well they're improving working efficiency or patient satisfaction. The future research should also continuously look for innovative information technology applications that could disrupt the field. An example of such a technology is augmented/virtual reality: they were introduced as a concept in the dental health care exhibition in Helsinki, and also Vottonen (2017) stated in her interview that AR/VR could improve e.g. the treatment planning in the future.

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