CHALMERS
UNIVERSITY OF TECHNOLOGY

Digital Dentistry with Additive Manufacturing in Sweden

Implementation, Roadblocks and Business Opportunities

Master's thesis in Product Development

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Department of Industrial and Materials Science
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2019

Master's thesis 2019:NN

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Cover: Author Johan Östblom getting his teeth scanned with an intraoral scanner at Tandläkarna Löfström

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Abstract

The dental market is in progress of getting digitalised, which means machines and methods are getting replaced. This opens up opportunities for new actors. The aim of this Master Thesis was *to explore Additive Manufacturing in Digital Dentistry in order to develop a business proposal fitting a consultancy company.* This was achieved with an exploratory study, which begun with literature review, interviews, and study visits. Interesting areas were investigated further which resulted in business proposals that were eliminated together with the initiating company. It was concluded that commercial AM of Zirconia crowns still is years away. The surviving two proposals, 'Bites2Bytes' (helping studios to digitise) and 'Scan-van' (offering digital solutions when needed once in a while), were confirmed and improved by an online questionnaire reaching 160 respondents on the Swedish market. Here 'Bites2Bytes' was concluded to be the stronger option. Further, it was found about half of the dental studios (non-private ones, Folktandvården) could not themselves decide about digitalisation, because it is decided higher up in the business hierarchy, so the focus for smaller consultant firms should be on private studios. The market survey indicated there indeed is business opportunities right now on the Swedish private dental market. Future work entails to further develop the Bites2Bytes service with close communication with or with a live test with a real dental studio.

Keywords: dentist, digital dentistry, additive manufacturing, review, business opportunities, digitalise, digitalisation

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Carl N.K. Toller
Market survey respondees
Emotional support from families and friends

David Löfgren and Johan Östblom, Gothenburg, March 2019

Contents

Glossary

Digital Dentistry
: defined in a broad scope as any dental technology or device that incorporates digital or computer-controlled components in contrast to that of mechanical or electrical alone [1].

Additive Manufacturing
: (AM), a process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies [2].

Bridge
: also bridgework, a piece of material that contains one or more artificial teeth and is kept in place by being fastened to the natural teeth [3].

CAD
: abbreviation for computer aided design: the use of computers to design objects [3].

CAM
: abbreviation for computer-aided manufacturing [4].

Crown
: The (dental) crown is the section of the tooth that is above the jaw-bone.

Odontology
: the scientific study of the structure and diseases of teeth [3].

SME
: Small and medium-sized enterprises (SMEs) are businesses whose personnel numbers fall below 50 for small and 250 for medium size [5].

1

Introduction

Digital Dentistry is expected to undergo a significant growth [6]. This leaves room for new business opportunities. The authors' hypothesis is that Digital Dentistry (here mostly CAD and CAM) is in the early majority adoption phase when looking at the Law of Diffusion of Innovations [7], see Figure 1.1. Dental studios have had time to look at other studios successful digitalisation and seen that the technology is proven and have enough benefits, to consider an investment. However is it the right choice for them? Taking the digitalisation step may be time-consuming, with a costly starting fee, and require a choice among a multitude of different options. New business opportunities are interesting for all consultancy companies and especially start-ups that need to develop their expertise and position themselves on a market. For a consultancy company that specialises within Additive Manufacturing (AM), the spread of Digital Dentistry is essential for them to start in the dental field. Low volumes, complex surfaces and the high degree of customisation (often volume of one and unique) makes dentistry a good match for AM [8].

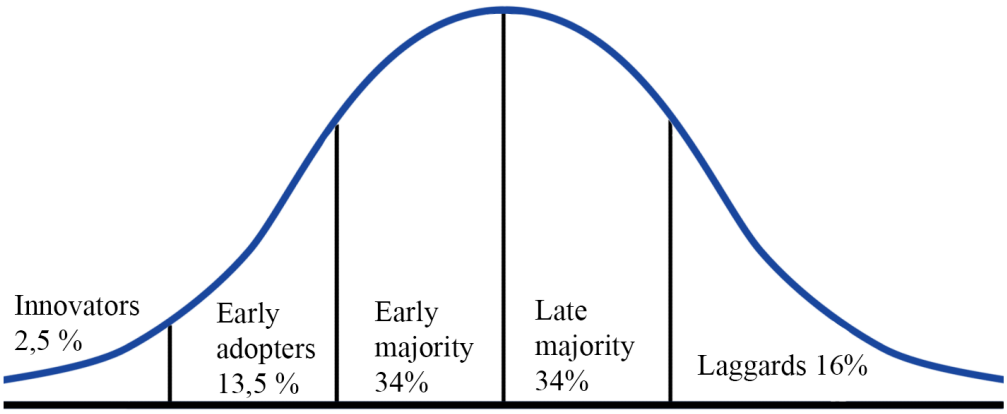

Figure 1.1: The figure shows how consumers on a market adopts a new technology or product, according to 'The law of diffusion[7] (illustration by authors, inspired by [9])

1.1 Market background

This thesis was initiated by a start-up consultancy firm named Hononga AB. The firms focus is AM in particular and product development in general. The company is interested in areas where AM is being implemented or expanded to find business opportunities in order to position themselves on the market. It is important for Hononga's growth to increase their understanding in new potential markets, subject to growth and expansion in AM. To see which stakeholders there are. In this case, AM is expected to grow within Digital Dentistry that in return is expected to experience a big growth. The global market of Digital Dentistry is expected to grow about 8.1 % annually (from 2016 to 2027) and Europe holds the largest market share of 42.2 % [6]. Hononga has noticed this growing trend of AM within Digital Dentistry and therefore sees the potential of establishing a business for their company. According to Roland Berger, the Manufacture readiness level of AM in the medical field is 8-9 (Introduction to AM tech EPMA). Based on this, digital dentistry is considered to be a suitable field to explore. This is why from Hononga's viewpoint this thesis has a meaningful purpose and an exploratory study is highly valuable in search of suitable business opportunities within the field.

1.2 Basic dentistry

In order for the reader to be able to understand the field of dentistry and the authors reasoning, a brief overview is given. The thesis mainly regards the Odontology parts of dentistry because most of the content and dental products that are connected to AM where found here.

The oral cavity is located inside the human head and is in a more common tongue known as 'mouth'. See Figure 1.2 for the oral cavity's different parts. Dentistry first and foremost focuses on the teeth within the oral cavity, there are however specialists who work e.g. with surgery related to the jaws. An adult with a normal oral cavity has 28 teeth, this does not include potential wisdom teeth [10]. The teeth are classified into four quadrants and each quadrant holds seven teeth. In order to easily communicate which tooth is regarded, there is an intuitive numbering system for the teeth. Quadrant 1 is located in the upper right jaw, number 2 in the upper left jaw, quadrant 3 in the lower left jaw and the 4th quadrant in the lower right jaw. In the quadrants each tooth starts with number 1, starting from the centre line going down from the nose and increasing towards the ears. Together these forms combinations such as 1.1, 3.2 and 4.4. For example, 1.1 and 2.1 is the two front teeth which are located in the upper jaw [11].

A tooth is divided into different regions, which may be seen in Figure 1.3. As seen in the figure, the enamel and dentin are protecting the pulp, nerves and blood vessels [14]. This implies that the Crown part of the tooth needs to be in good condition in order to avoid tooth discomfort and pain. That is why solutions such as an artificial

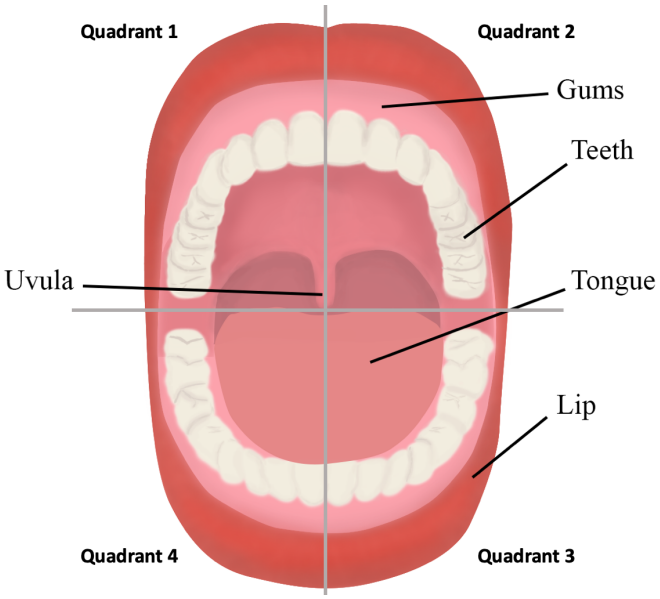

Figure 1.2: Figure illustrating the oral cavity's different parts (illustration by authors, inspired by [12])

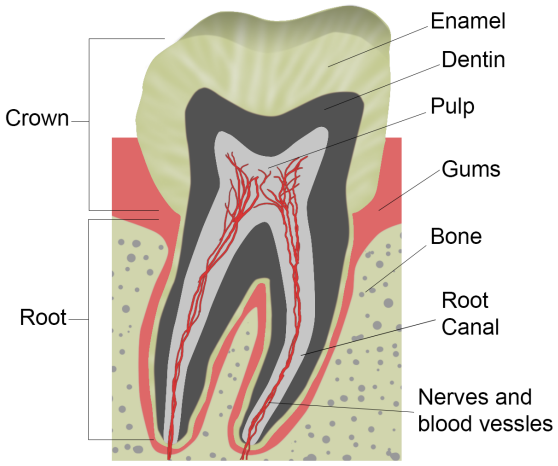

Figure 1.3: Figure illustrating the tooth anatomy (illustration by authors, inspired by [13])

crown replacement, which is highlighted in this report, could play an important role. One should always strive to preserve and restore a tooth (using fillings or artificial crown) and only as a last resort have the tooth removed. This is due to the fact that having an implant put in, is a more invasive and complicated procedure.

1.2.1 What are dentists?

Dentists are doctors that specialise in the patient's oral health. Their expertise areas in addition to teeth and gum are muscles of head, neck, and jaw, the tongue, salivary glands, and the nervous system of the head and neck. Common responsibilities include: diagnosing and treating of oral diseases, monitor the development of teeth and jaw, surgical procedures of teeth, bone, and tissues of the oral cavity. This report focuses on procedures involving teeth. Education and certification are required in order to work as a dentist. A big part of dentists is solo practitioners, owning their business, with a staff of dental assistants, dental hygienists, and sometimes lab technicians. Many dentists continue their education while working and specialise within an area [15] [16].

The physical location where the dentist performs their trade is in this report called dental studio. Most of the dental studios do not have their own manufacturing of dental products (such as artificial crowns, surgical guides, etc.), instead, they have collaboration with dental labs. Some extra difficult milling procedures the dental lab might send to a milling centre company, which are able to perform more advanced tasks than a regular dental lab. [17]

1.3 Aim

To explore Additive Manufacturing in Digital Dentistry in order to develop a business proposal fitting a consultancy company

1.4 Study objectives

To fulfil the aim and find business opportunities for consultancy companies, an underlying literature review was made and process flows were mapped and compared between the state of practice and state of art (Digital Dentistry methods). The thesis investigated the implementation degree and also aimed to identify possible roadblocks which hinder the development of AM within the dental field. Hence, the study started with a wide scope which narrowed down during the progress of the thesis with an elimination choice to investigate some of the business opportunities identified.

The research question is: *Is there a profitable business opportunity for a consultancy firm on the Swedish dental market following the digitalisation wave?* This is akin to the title of the thesis as well as the aim.

To help answer the research question two overarching questions were constructed. Due to it being an exploratory study the aim and these questions have been modified during the course of the thesis.

RQ1. When will AM of Zirconia crowns be commercially available?
The firstly stated research question is linked to a business opportunity because with new technology, there come new opportunities. AM is interesting due to the comparison with the current state of practice, milling. This because there are key aspects which sets them apart such as sound level, price, speed, size and work environment. In order to gain further knowledge to answer this research question, a follow-up question has been stated:

- For in-house production in a dental studio, is AM or milling better?

RQ2. Why are not more dental studios digitalised?

The second research question is aimed at exploring the digitalisation and to investigate possible business opportunities which are suitable for a consultancy firm. A set of sub-questions have been stated in order to gain more knowledge:

- Where is AM used, or may be used, in Digital Dentistry?
- What arguments are there for dental studios to digitalise?
- What roadblocks are there?
- What do the dental studios need help with?

1.5 Limitations

The thesis was limited to study the needs and opportunities on the Swedish market. International conditions were only investigated through literature studies. Moreover, the thesis was primarily focused on mapping the workflow and investigating the process of getting a crown, since it is a common procedure in dentistry and includes modelling, design and manufacturing of a dental product. Furthermore, the thesis did not develop any software. The thesis was conducted between 3 September 2018 to 20 January 2019. The budget for the thesis was set to 15 000 SEK.

1.6 Intelligence studies

Actors on the market of digitalisation of the dental market is machine manufacturers that is trying to push the new technology to the dental studios. Also companies that offers a complete digitisation service where the dentist can buy their intra-oral machine and get the choice of which connected dental lab to send the scanned files to which manufacturs the required dental products (e.g. 3Shape and Sirona). There is also an actor that actually took the name of 'Digital Dentistry'. Based in Iran they

are also known by the name DigiDen. They are in the industry of selling machines and supplies regarding Digital Dentistry (See webpage: digiden.ir).

1.7 Outline of the report

The remaining parts of the report are structured as follows.

Chapter 2 - Methods

Here the methods used are presented and motivated. The methods are for both the thesis and the resulting service. This gives an understanding of how the structure of the work of the thesis and service is built up.

Chapter 3 - Theory

To explain what Digital Dentistry is to the readers, and to set the base of the thesis exploratory study, the first four sections explore what kind of digitalisation exists today. Extra focus is put on artificial crowns, partly because this is a big part of dentistry, and partly to stand as an example of analogue versus digital methods because the workflows include the whole chain of modelling, design, and manufacturing of dental products.

The following sections are used for looking for business opportunities by investigating AM in similar fields, and thereafter in which new areas AM could be implemented in dentistry. The dental market is also looked at in general, and other dental digitalisation areas are stated in order to support a complete digitalisation service.

Chapter 4 - Results

In the first two sections, one identified possible AM method that is underway was explored more deeply. Thereafter other business opportunities where identified, terminated/developed, confirmed with a market survey, and tested. Lastly, the effects on the environment by digitalisation is looked at.

Chapter 5 - Discussion

The research questions are revisited and the results of the thesis are discussed with some recommendations.

Chapter 6 - Conclusions

The general conclusions are presented, and lastly, recommendations of future work are given.

2
Methods and planning

In this chapter, the overall planning of the thesis with which methods will be explained and thereafter go into specific areas.

2.1 Overall structure

The overall structure concerns the fundamental work methodology which lies as the foundation for the thesis. The concepts mentioned in this section has thereby structured the thesis on a macro level and not been detailed down to day-to-day basis. The overarching method used was Double Diamond, although with the last step from 4-D method added. The planning have been put in a living Gantt-schedule document. Data collection have been made through observations and interviews as well as literature reviews. From the information gathered the process mapping was done and business research conducted. Halfway through the thesis, the first stage-gate was set. To proceed, a list of requirements were needed to be met and it was discussed with the initiating company, as to what area to focus on. Six suggestions of possible pathways to take were presented in a PowerPoint with SWOT-analysis, see Appendix D. The decisions made at the gates were made in discussion with the initiating company as well as the main supervisor. Although ultimately it was the authors choice. A choice to combine two areas were made and an action plan with three steps was set up (included as suggestion 7). Step one was to compare two manufacturing methods, step two was to suggest a business proposal for one of these and step three was to validate the proposed business solution.

2.1.1 Gantt schedule

In order to keep track of the planning and to what extent the thesis has fulfilled the desired deliverables, a Gantt schedule was created [18]. The schedule was based on the overall planning from the modified Double Diamond model, the Stage-gate model and the deadlines which were provided from the University. Due to the fact that the thesis had a fixed starting and ending date the activities within the thesis were planned by using reversed scheduling. This set the duration time for each stage and sub-task by going backwards from the end date and filling in the intermediate tasks until the beginning. For the final Gantt-schedule see Appendix A.

The Gantt schedule was chosen since it is a well known tool which enables a quick and easy graphical overview of the time-plan of the thesis. Moreover, the Gantt schedule

breaks down the thesis into activities which makes the thesis and its deliverables more graspable. It was also chosen since it is a living document which enables to keep constant track of the progress of the thesis, to what degree the time-plan was being followed and to what extent each set activity was being fulfilled.

2.1.2 Double Diamond

For the overall planning of the thesis, the project management method Double Diamond was chosen [19]. The method consists of four phases: Discover, Define, Develop and Deliver, see Figure 2.1. In the figure inside of the diamonds the focus of the thesis is written, which modifies how the method was used somehow. Further, the Double Diamond method is missing thorough documentation, which was considered a critical part of the thesis overall structure. The authors, therefore, added the last phase of a similar method, the 4-D model [18]. The 4-D model method uses four phases: Define it (the thesis), Design it, Do it, and Develop it. The last phase of the 4-D model is an analytic phase aimed at documenting and improving upon the completed project which complements to the Double diamond method. Further information about the 4-D model is given in Section 2.1.3.

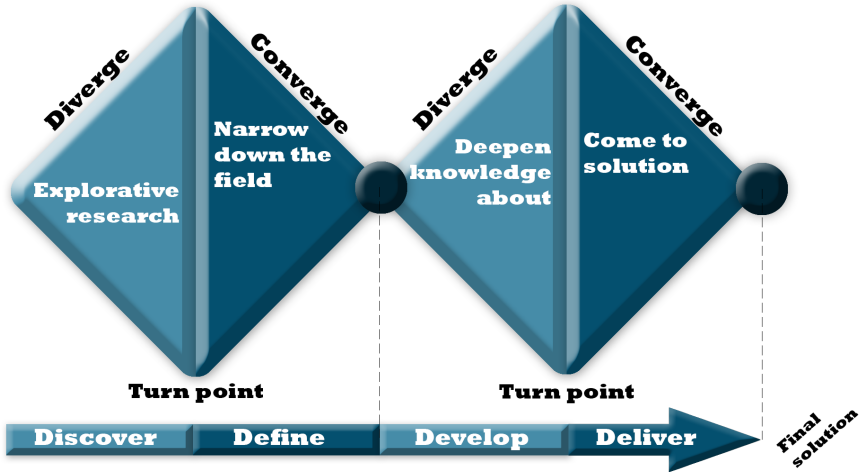

Figure 2.1: The figure illustrates the four phases of the double diamond design method, with the focus of the thesis added inside the diamonds (illustration by authors, inspired by [20])

The Double Diamond method was chosen as the primary project structure for this thesis instead of the 4-D model due to the nature of the thesis, the thesis being an exploratory study, which required a big focus on the Discover phase where an extensive literature review, study visits and interviews were made. The literature review had its starting point in key search words, such as "additive manufacturing", "Digital Dentistry" and "intra oral scanner". Included in the literature research was fundamental research regarding dental processes and terms which set the foundation of the thesis. The search field was then expanded and deepened based on the found

research and the evolvement of the master thesis. Study visits were conducted in order to get practical understandings for the dental field as well as potential variances between different dental studios. Interviews was held with professionals related to the fields dentistry and additive manufacturing, and consisted of both structured and non structured interviews This was done in the search for an area with improvement potential which in return decided the shape of and narrowed down the scope.

The double diamond is a suitable method for projects where there is not a predefined path. This is due to the fact that the method is based on diverging and converging thinking which allows the project to vary in its scope and thereby cope with uncertainties that comes with explorative projects such as the one conducted in this thesis. However, there was felt a need of having clearly stated objectives and some sort of estimation of where the thesis would be heading and not be as agile as the Double Diamond method might suggest, which is why tools such as Stage-Gate model and 4-D model was incorporated to cover the gaps that were considered to be with the Double Diamond method.

2.1.3 4-D model

The 4-D model [18] is a project management tool which offers a clear, and easy to follow, process. It is used to state the aims, objectives and outcomes of a project, which are essential parts in order to have a successful project. As the name suggests, the 4-D model consists of four steps:

- **Define it**
  In the first step of the 4-D model, the focus is to create an understanding of the project and what the end result of it should be. Furthermore, in this part of the process, the aims of the project and defining the objectives which will achieve these aims are to be made. Major milestones and key stages of the project is also set in the part of the 4-D model.
- **Design it**
  The main objective of the "design it" step is to concretize the work in the previous step and to set up the plan for achieving the set objectives. A time plan of the required time for the project should be defined as well as preparing for a way of tracking and monitoring events in detail.
- **Do it**
  This is the part of the project process where the product/service is being developed and needed activities are carried out. In this phase, it is also needed to review to what level the time plan is being met, so that possible delay is met with countermeasures.
- **Develop it**
  The finishing phase of the 4-D process, this is the finishing step where the project is shut down, fully completed, documented, and analysed. Feedback and insights of possible improvements may be collected. It is also important in this step to evaluate and measure the results comparing to the aims which were set early on in the process. Lastly, the highly important part of the

"Develop it" step is to review and learn from the project that has been carried out. This way, the next time a project is carried out lessons learned will be utilised.

As seen in the motivation of the Double Diamond, the 4-D method was not chosen as the primary method because of the nature of the explorative study. However the important 'Develop it' step is taken.

2.1.4 Stage-gate model

The thesis was also planned with the Stage-gate model [18], see Figure 2.2 for the thesis initial Stage-gate plan. The method was chosen due to it being a process that is easy to follow and makes sure that the time-plan and required progress is being fulfilled. The method is also beneficial since it forces the elimination of alternatives and/or paths, which ensure that the focus of the thesis is set on the most promising area. However, it is important to have the gates placed correctly, otherwise, there is a risk of spending too much time and energy on ideas that are not promising, which may only become apparent when being reviewed at the next upcoming gate. Without deliverables throughout the project, it would have been easy to make the mistake of working towards the wrong focus or underachieving goals. On the other hand, it is not beneficial to include too many gates in a project since they allocate time from the progress of the thesis by requiring time for conducting an analysis of suggestions. The numbers of gates and their placement, time-wise in the thesis, must be balanced. It's also important to not let the Stage-gate method control too much in an explorative environment, in order to still be agile. Though due to the limited project time, still know when to decide it is time to develop the remaining most promising area.

The purpose of the gates was to:

1. Review initial plans and estimates, to check if they are still valid or in need of change
2. Take decisions concerning direction/area, or between alternatives the project should be pursuing

2.1.5 Kotter's 8 steps change process

Dr. John Paul Kotter developed his process, "Kotter's 8 step process for leading" which can be applied for multiple of settings but was in this project used for supporting the transformational change which the dental studios would have to go through in order to transit from a old state (analogue tray technology) to a state of art (intra oral scanning technology). The process was chosen and incorporated into the work in this project since it highlights important factors and provides with a solid foundation for change within a organisation.

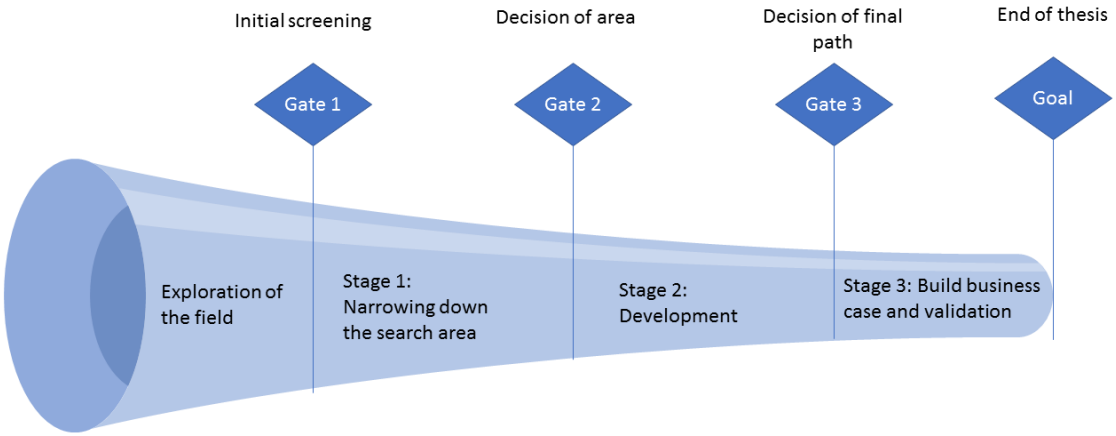

Figure 2.2: Stage-gate model illustrating the thesis' general structure, (illustration by authors, information from [18])

Kotter's 8 step change process, as the name implies consists of eight steps, which are [21]:

- **Step 1: Create a sense of urgency**
  Make affected people realise the need and urgency of making a change, and why the change is needed.
- **Step 2: Build a guiding coalition**
  It is important to form and gather a group which will take lead of implementing the change, which will plan, guide and successfully communicate to the remaining part of the organisation.
- **Step 3: Form a strategic vision and initiatives**
  In order to create motivation within the organisation, this step is used to clarify how the future will be as compared to the past and by doing so also make the organisation realise the benefit of changing.
- **Step 4: Enlist a volunteer army**
  Step 4 highlights the importance of getting people on board with the change, massive changes requires that the large majority is moving in the same direction or else there will be no change.
- **Step 5: Enable action by removing barriers**
  By opening up the landscape and remove barriers which hinders the development of the change, the real and efficient change can properly begin.
- **Step 6: Generate short-term wins**
  It is important to track progress and highlight small, short term progresses, since this will energise and motivate the people to stay true to the change work.
- **Step 7: Sustain acceleration**
  In order to not loose pace after the first success within the change process, step 7 is used to highlight the importance of always working hard for the change and not slow down after early wins.
- **Step 8: Institute change**
  To keep and protect the newly implemented changes, it must be made sure that the new habits are stronger than the old ones so that the organisation

does not fall back into the old and unwanted behaviours.

In the setting of this project the main focus have been on the steps 2, 5, 6 and 7. This was due to the fact that these parts of the model was considered the most relevant for the project's application and that the model well supported the transition/service the project ultimately proposed.

2.2 Planning and communication

On a weekly basis, the thesis was planned using weekly to-do lists. In these weekly documents, tasks were listed what to do, when, and by whom. The structure of the weekly to-do lists aimed to follow the structure of SMART : "**S**pecific and written down, **M**easurable, **A**chievable, **R**ealistic, and **T**ime-framed" [18]. Early on, weekly and bi-weekly meetings were set up with the supervisors at Hononga and the University. Later a Communication plan [18] was set up, see Table 2.1.

2.3 Literature review

To provide a fundamental knowledge within the area of dentistry some of the literature reviews are about the basic dental operations and definitions. A more advanced summary and consolidation of relevant literature were developed in order to shed light on which state AM is within the dental field today and get inspiration for the explorative part. This was achieved by retrieving literature from online sources mainly (e.g. pubmed.gov). By consolidating today's research, a new broad and condensed source of information was obtained. When a better understanding of the dental field had been obtained, more technical literature research began. Which included, among other things, the accuracy of intraoral scanners, material characteristics of 3D printed ceramics.

Table 2.1: Table of the communication plan used throughout the thesis

Person	Role title	Frequency	Format/Channel	Notes
David Johan	Authors	Daily	Meeting	Weekly Progress Reports for all
Ola	Main Supervisor	Bi-weekly	Meeting	
Eduard	Co-supervisor	Requested	Meeting	
Vito Simone	Company	Weekly	Meeting or Skype	
Carl	Opposition	Requested	Email	
Per	Support	Requested	LinkedIn	

2.4 Observations and interviews

A big amount of time of the thesis have been about getting in contact and upholding contact with all sorts of persons connected to dentistry and/or AM. Observational studies and interviews were carried out in order to understand the associated processes within dentistry to map these and identify possible business opportunities when observing e.g. supply chain which is related to the process flow. Also, investigations how theory differed from practice, e.g. modified equipment. It was decided to be done observations both at dental studios with patients, as well as observing the manufacturing of dental products at a dental laboratory. Quality interviews and observations were conducted in the first half of the thesis duration which after analyses gave data. To confirm these results, the resulting service constructed, and also gather further data, a quantity study was done by sending out a questionnaire digitally.

The observations were made in a non-interfering way. Notes where taken with pen and paper to avoid using computer or voice recorders which may be perceived as unnerving by some, which could lead to less open answers. Clarifying questions were tried to be stated as neutrally as possible. As an observant it is of key importance to interfere as little as possible to not impact those studied, otherwise, there is a risk of getting a polished version of the true experience and hence not get the full story. It was with respect to this that the chosen methods were used.

2.5 Process mapping

For the dental procedure of getting a crown replacement mapping of processes and graphically illustrations of the flow of physical objects and information flow in the system were made. These mappings were based on study visits at dental studios where the processes were observed and questions to the dentist and assistants were asked. This enabled the first-hand view of the processes in practice which helped to get a better understanding of how the flows work and how well it works. Moreover, the patient's experience could be observed during the procedure. The process mapping method IDEF0 was chosen and is described in the following section.

2.5.1 IDEF0

There are multiple ways of illustrating process flows but a structured and intuitive method of doing this is a method called IDEF0 [22]. The method was chosen to illustrate the processes due to it being a well-used method that suited the needs well with a consistent and structured deployment of the mapped processes. Further, it was chosen since it may easily be read and understood by those who are previously not familiar with the method, it contains a lot of information about the process, and it may be adapted to virtually any context.

As seen in Figure 2.3, the IDEF0 model consists of four parts which help with structuring various inputs and outputs of a process step, by dedicating a direction

from which they enter the process step.

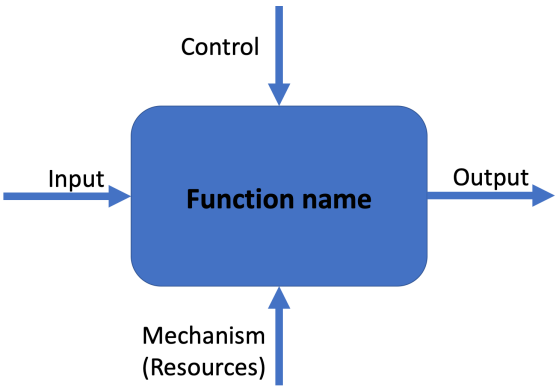

Figure 2.3: Figure of building blocks of the IDEF0 (illustration by authors, information from [22])

In addition to the workflows of the dental employee's actions, a customer journey roadmap was constructed in order to understand the needs and wishes of the patient. A customer journey roadmap aims at illustrating the customer's experiences, expectations and it's level of pleasure throughout the process which it undergoes and not just look at the process itself as the workflows do. The customer journey map is explained further in Section 2.7.2.

2.6 Decision handling

Since this thesis has been an exploratory study, a large portion of the thesis has been to handle which area to investigate further and which paths to pursue. Therefore, it existed a need for a tool which helps the authors to make less biased decisions. Early on, it was decided to use SWOT for this since it is a well known, tested and unbiased tool that meets the needs of the thesis. This because it still works well when the possible paths are very different which makes it harder to compare with other methods, such as a Pugh matrix [23]. Decisions were also to some degree made in discussion with the initiating company and Chalmers supervisors, however, the authors always had the final decision.

2.6.1 SWOT

Strengths, **W**eaknesses, **O**pportunities, **T**hreats (SWOT [18]), is a structured way of analysing ideas or concepts and acts as a helping tool with taking decisions. The method aims at targeting four different perspectives and thereby present a more objective way of analysing, see Figure 2.4. The Strengths section aims at highlighting what strengths the suggestion has, and why that particular suggestion is a good choice. As a counterforce, there is the Weakness section which highlights weaknesses with the suggestion and why it might be a bad alternative. The Opportunities section focus on what potential there is and what positive outcome the suggestion could

have. Lastly, there is the Threats section which is the counterpart of the opportunities section and aims to highlight what possible factors could disturb or affect the suggestion in a negative way.

Figure 2.4: Figure illustrating the SWOT model (illustration by authors, information from [18])

SWOT was chosen to be used since it is an intuitive tool which allows for an objective view of the presented paths or suggestions which were developed throughout the thesis. SWOT was used as a part of the gates. Multiple ideas of the interesting paths were presented at the second gate, with the aid of SWOT, the most lacking paths could be identified and eliminated. These SWOT analyses may be found in Appendix D.

2.7 Design of service

A part of the thesis has been designing and developing a service which is intended to help Dental studios to further digitalise their work-flows. In order to fulfil the desires of the dental studios and also add value to the customer, a number of useful tools and methods have been chosen and used. These will be presented and explained in detail below, in order to justify their usefulness and why these methods were chosen. Further then Double Diamond that is mentioned in Section 2.1.2, Brainstorming, Customer journey map, and Market research has been used.

2.7.1 Brainstorming

Brainstorming is a group effort to find a solution to a stated problem. Alex Faickney Osborn introduced brainstorming as a creative technique the year 1942. With the aim to have freedom of mind and creative thinking. He introduced four rules [24]:

1. Do not criticize ideas
2. Encourage producing a wide array of ideas
3. Build upon others' existing ideas

4. Motivate sharing wild and unconventional ideas

The method was chosen because it is a fast method to come up with divergent ideas that with more methodical methods otherwise might have been overlooked. Further when analysing more formal methods may be used.

2.7.2 Customer journey map

A customer journey map graphically illustrates a customer's perspective of a service/process and it allows to identify steps of a process where there is room for improvement appreciated by the customer. [25] It is an important tool since it puts focus on the end user rather than developing a service from a pure business perspective. By having the knowledge of how a customer experiences a service/process and also identify its expectations and experiences, it provides favourable prerequisites for developing a good and desired service. The tool was chosen because it gives a good understanding of the customer's perspective in a process. Ultimately it is the customer/patient that is the driving force in many decisions taken by a dental studio, which makes it crucial to understand their perspective. In contrast to simply collecting statements of patients of how their expectations and experiences in a process are, the customer journey map allows data to be graphically illustrated and easily understood with the help of a comprehensive overview. Further, it was chosen since it may clearly illustrate weak points in the process (as seen from the patient side) and it also enables to visually display opportunities.

In the thesis work, the map has been used to identify the expectations, experiences and needs of a patient which is in the process of getting an artificial dental crown. The journey map has been based on study visits which were conducted at dental studios with real patients who were in the process of getting a crown installed. The journey map has also been based on one the author's own experience after going through both processes (digital scanning and impression) at a dental studio by a dentist. The customer journey map may be found in Appendix C.

2.7.3 Market research/questionnaire

In order to be able to identify confirm and further develop business opportunities on the digital dentistry market, market research was conducted in the form of a questionnaire that was sent out to dental studios, both privately owned as well as Folktandvården (the publicly owned). It was done with the Google Forms software. The questionnaire consisted of $14 - 16$ questions (depending on what answers was given by the respondent), which included multiple choice questions, check-boxes, linear scales with a $1 - 4$ rating (see example Figure 2.5) and free text questions. The majority of the questions had an option of adding an alternative free text-based answer in order to allow for alternative answers as well as capturing qualitative based answers. The linear scale rating questions were designed to have a scale of $1 - 4$ to avoid respondents choosing a midway answer of for example 3 (on a $1 - 5$ scale) since such an answer does not force the respondent to choose between like or

dislike something.

Figure 2.5: Linear scale question which was part of the questionnaire (produced with Google Forms)

2.7.4 Business Model Canvas

In order to get a better understanding of the various stakeholders which would be in contact with a potential service, the Business Model Canvas (BMC) tool was used [26]. It was chosen due to it being a visual tool, which with a structured way, enables a good overview of a stakeholder's business and its relations. Several BMC models were created in order to get an understanding of each stakeholder and also in what ways the stakeholders are connected. Further, by knowing each stakeholders business and relations, it is possible to find potential gaps or areas which could open up for a new market. BMC is a tool which is used for strategic management and may be used for both start-up companies, as well as well-established companies. The model aims at providing a business understanding for the company by looking into the four major areas of the company. These are infrastructure, customers, finances and offering. By answering a set of sub-questions related to these areas, the company's business may be inspected of a general basis which also may highlight potential risks or advantages the company have. The model is filled preferable done together with a set of people of the relevant company/stakeholder, in order to include more potential aspects of the business. In each section of the model (seen in Figure 2.6), there are questions such as *"which are our key partners?"*, " *"which customers are we targeting?"* and *"what are our main costs in our business model? "*. By answering and filling out the Business Model Canvas, a good general understanding of the company's/stakeholder's business may be given.

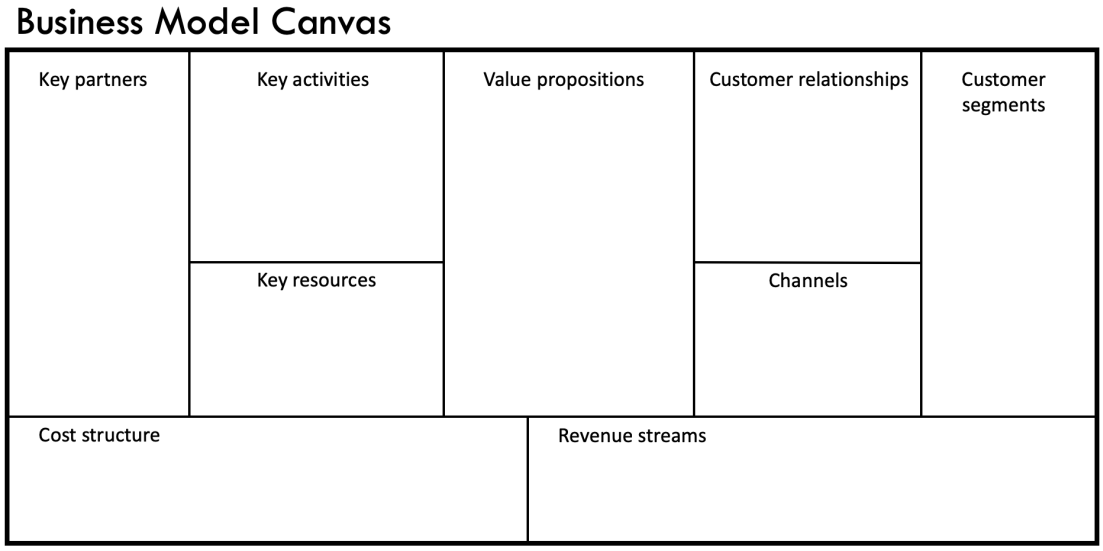

Figure 2.6: Figure illustrating the Business Model Canvas (illustration by authors, information from [26])

3

Digital and analogue technologies for dental applications

In order to create dental products, models of the oral cavity need to be constructed. In the following sections first, the analogue method is explained and thereafter the digital method. Design and manufacturing of artificial crowns are presented as an example of the difference in the dental processes between analogue and digital. Furthermore, dental methods making use of AM are looked into as well as AM in similar fields. Future implementation for AM in dental methods is looked at. Research about the dental market with its economic aspects is presented. Lastly, digitalisation areas outside of AM, which are good for consultancy companies wanting to present a complete service, are listed shortly.

3.1 Analogue dental modelling

The analogue way of taking an impression of the teeth is done by using alginate or silicone as impression mass which is able to produce a detailed negative model of the teeth. As a start, impression trays which fit the patient well are selected and mixing of the impression material may begin, see Figure 3.1. After a clean up of the teeth and blowing the mouth dry with compressed air, the trays are filled with impression mass and the patient bites the tray. A few minutes of waiting for the material to set and the tray is removed from the mouth. The same process is repeated for the other jaw [27]. See Appendix B for the work-flow of the state of practise modelling.

3.2 Digital dental modelling

To make digital dental models scanners are used. There are two types of scanners commonly used within dentistry. Intraoral scanners are typically found in dental studios, and tabletop scanners are typically found in dental labs. These are separately explained and thereafter the digital files extracted from these are investigated.

3.2.1 Intraoral scanners

The intraoral scanners are hand-held devices which are shaped similarly to a toothbrush which easily fits in the mouth. These scanners are either wireless or connected by wire to a computer which processes the collected scanning data and then displays

Figure 3.1: On the left is an impression tray with impression mass, and to the right is a bowl with impression mass (photo taken at Tandläkarna Löfström)

the teeth and gum on a display. This is seen on the front page of this report. To create a completed model of the oral cavity three scannings are done and put together. First either the upper or lower jaw is scanned, next is the other jaw scanned, and lastly, the patient is asked to bite together as she normally does and the bite is scanned. The bite is scanned in order to put the two digital models together to give information about the design of the dental product. This is the digital version of an articulator.

3.2.2 Tabletop scanners

Tabletop scanners are used for converting alginate impressions into a digital 3D model which is used to digitally process the production of the crown, bridge, or other. This is common in dental labs in order to digitise information (impression of teeth) sent from dental studios [17]. In Figure 3.2, a tabletop scanner is shown. An impression is placed in a fixture and then scanned using a laser in order to create a 3D model which later are used to make, for example, an artificial crown or a bridge. There are numerous ways of doing this analogue to digital transition, the machine in Figure 3.2, has a fixed laser and then rotates the model in order to create the digital model. There is also another machine version that has the impression fixed while the laser is rotating around it.

3.2.3 Open source and proprietary file formats

There are two different types of file formats that may be exported from the scanner, an open source file format (.STL) or a proprietary file format which is unique to each manufacturer (for instance: Sirona uses .cdt and .lab while 3Shape uses .dcm) [28]. Open source files enable more flexibility of choosing which CAD/CAM software to use while proprietary file formats require certain software in order to unlock the

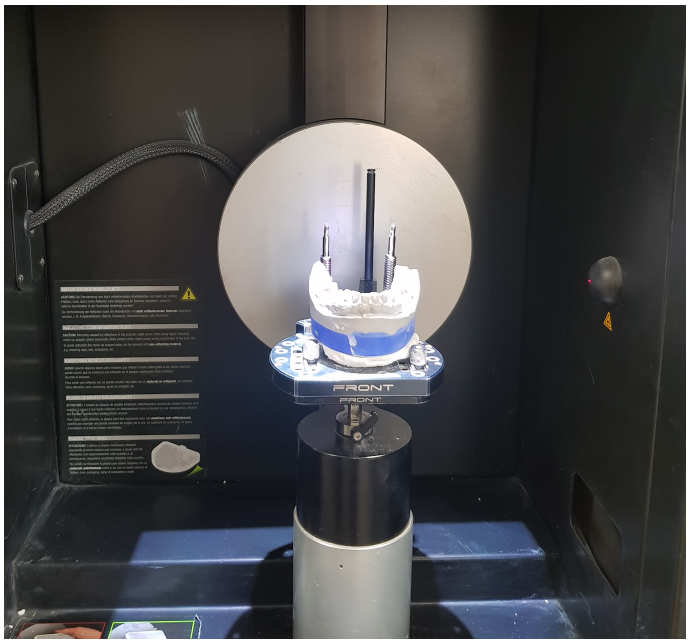

Figure 3.2: Picture of a tabletop scanner (photo taken at BrightDental in Jönköping)

encrypted proprietary file format. By having a proprietary file format, one creates a lock-in mechanism which limits the user to use software developed by the scanner provider, however, the benefit of having a proprietary file is if someone should come across the file, it can't be opened without having the correct corresponding software. This is important since the encrypted file usually contains more than just the data obtained from scanning, it may also hold patient information which needs to be protected. The currently mostly widely used format for the 3D model of the teeth is .STL format [29].This enables the dentist and dental labs to use a wide variety of software instead of being limited to a single, manufacturing specific software. Another aspect is that ".STL" can not contain any colour, which is helpful for the dental lab personnel when they are e.g. looking for the edge of the modified tooth, and distinguish it from the gums [17]. There however manufacturers which use other file formats in order to be able to include colour in the model.

3.3 Dental design and manufacturing

There are many factors to consider when you design dental products, both function and aesthetics are important factors. The functional aspects include: articulation, bite and life span [17]. Aesthetic aspects which also is an important factor that needs to be considered when designing an artificial crown or bridge, is that it should look realistic and be as close to a real tooth as possible. There are various types of materials which can be used for the crown or bridge, which all have their advantages and disadvantages. Patients seeks to have an aesthetically pleasing crown or bride and therefor the material of choice, porcelain (ceramic) is very popular [30]. This is due to it resembles a tooth both in colour as well as its possibility of having a grading

colour which looks very realistic, just like an actual tooth. An artificial tooth in gold for example, is not an realistic looking tooth and therefor not appealing for most patients, however its functional aspects are well tested and praised [30]. Moreover, the work of the dental technician is crucial, both in terms of function as well as aesthetics. The tooth or bridge needs to be thick enough to withstand the large biting force for years to come while it also should look realistic with colour grading, texture and size.

3.3.1 Analogue creation of artificial crown

In the analogue method, the design and manufacturing are happening in a circular manner by iteratively adding and removing wax material. The bite is analysed with the help of an articulator, the upper and lower jaw is put into a frame containing a hinge which simulates the patient opening and closing the mouth. When the designed model is finished the crown is casted by first investing it (encupsulate it with material), burning away the wax and then pouring in the melted material and casting it. Afterwards, the artificial crown is, among other things deburred, sintered, and painted. [17]

3.3.2 Digital creation of artificial crown

For the digital creation, the design and manufacturing are, in opposition to the analogue method, divided in a designing part and a manufacturing part. CAD is used to design the artificial crown. With the help of a virtual articulator, the bite may be analysed. CAM is used to set up the manufacturing steps, and then the crown is (normally) milled out and some after steps carried out including sintering and painting [17].

3.4 Identified dental methods which utilise AM

There are a variety of different applications within the dental field that currently uses AM. Below they are listed, and in the following subsections gone into deeper detail. To make use of AM in these processes a digital model of the oral cavity is needed. Which may be seen at Section 3.2. The methods all directly concerns teeth, although surgical guide instruments could have a broader application. The first section is about dental crowns, which may be replaced with an artificial part to a bigger or smaller degree. The second section is about the surgical guide instruments, that have been seen to mostly be used for the drilling in order to insert implants that artificial crowns may be attached to. Further bracers and retainers that are used to change the position of the teeth. Lastly is digital dentures that are used when the patient does not have any teeth at all.

3.4.1 Full and partial dental crowns

For various reasons an artificial crown, a "cap", may be placed over a modified existing tooth, illustrated in Figure 3.4. Similar to crowns are also bridges and partial

crowns: inlays and onlays. Because of the similarity, the focus will hence lay on crowns. The three most common reasons for adding an artificial crown are [31]:

1. When the tooth no longer may be repaired with fillings.
2. To protect a weak tooth which is close to breaking or keep a cracked tooth together.
3. To improve the cosmetic look, which could be due to an unsightly shape or discolouration of the tooth.

It requires a lot of precision to manufacture a crown which suits the patient perfectly. The precision of production is therefore of high importance, where (tens of) micrometres may have an impact of how well the crown fits the patient [17]. The material affects the minimum thickness needed on the artificial crown, hence some preparatory work by the dentist is needed which includes the existing tooth's height needs to be lowered. The tooth also needs to be shaped into a rounded cone shape with an angle of (approximately) 15°, in order to not have any overhang, which would make the threading impossible [32]. By the state of practice, the crown is manufactured by casting, the state of art use milling and/or AM. Right now AM looks like the future. Though it's good to keep in mind that milling is also fairly new on the dental market and is also improving [33]. By using laser sintering (AM) crowns in cobalt-chrome may be built up and afterwards be coated with ceramics. AM is also used to make study models with polymer extrusion where

Figure 3.3: Picture of a 3D-printed study model, printed from a Formlabs file (photo taken by authors)

the milled (and further processed crown) is placed and test-fitted [17], see Figure 3.3. Dental laboratories are moving away from this practice and it is getting more common to simply send the manufactured crown skipping the AM part [17] if it is a more simple crown. Further, an application for AM is to create temporary crowns to protect the modified tooth when waiting for the artificial crown to return to the dentist. State of practice is to with scissors cut an aluminium cap to fit the patient's tooth.

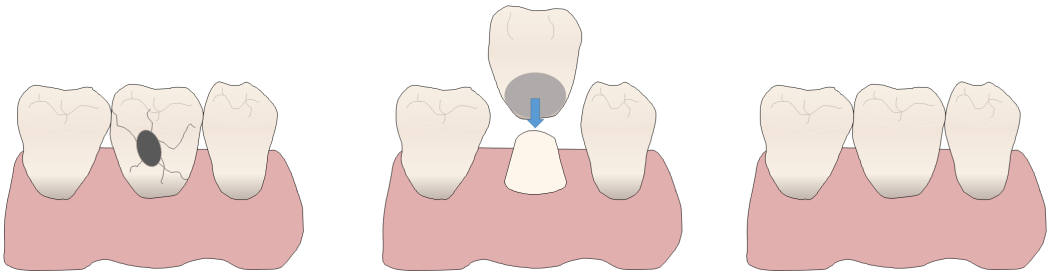

Figure 3.4: Figure illustrating placement of an artificial crown over a modified tooth (illustration by authors, inspired by [34])

3.4.2 Surgical guide instruments

When planning to attach a crown, Bridge or denture, the patient might have missing teeth or teeth which quality are too poor to use as a base, then dental implants may be chosen. Dental implants are inserted into the bone structure of the mouth, see Figure 3.5.

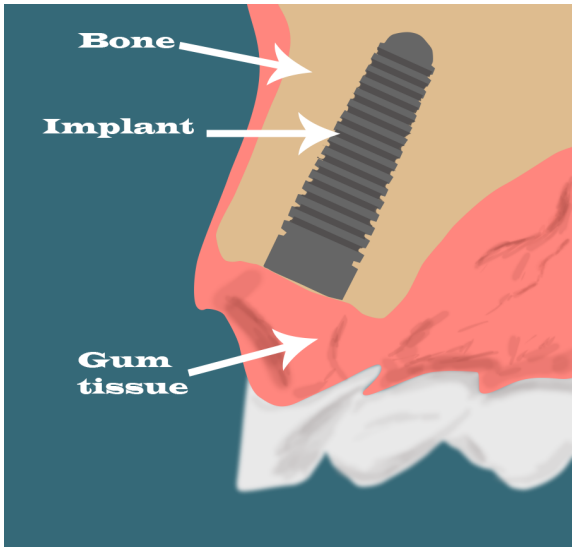

Figure 3.5: Figure illustrating an implant placed into the jaw bone (illustration by authors, inspired by [35])

Due to the high porosity of the bones, the angle and depth are crucial when drilling. This is another field where AM may be implemented by 3D-printing surgical guides and thereby reduce the variation in accuracy which otherwise occurs when a dentist drills by freehand. Having that said, such version of a guide may be designed in two ways, a partially restricting way and a completely restricting guide [28]. A partially restricting guide has the starting position of drilling restricted and the angle and depth are chosen by the dentist. A completely restricting guide leaves no possibility of variation for the dentist and instead fully restricts the path and depth of the drill [36]. A clinical case study has shown that the implant position tolerance has been improved by using fully restricted guides as opposed to doing it by freehand or using

traditionally manufactured guides [37].

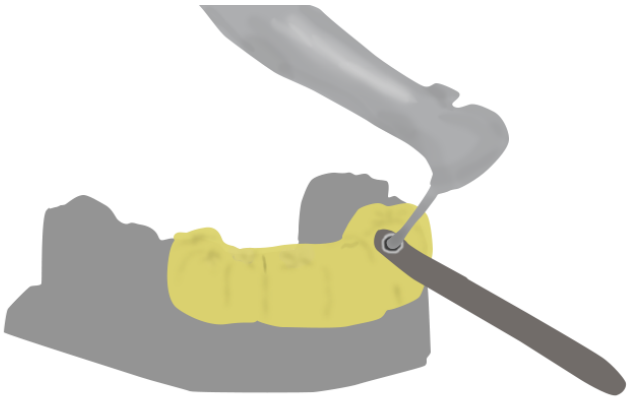

Figure 3.6: Picture illustrating a guiding tool for drilling (illustration by authors, inspired by [38])

As seen in Figure 3.6, the drill is only able to pass through the predetermined hole, which significantly improves the position of the later placed implant and helps the dentist to drill when it otherwise may be difficult. A study measured the improvement to go from 2.0 - 2.5 mm (freehand) down to 0.9 - 1.0 mm (fully restricted guide) in deviation from target placement [28].

3.4.3 Braces/Retainers

There is another application area for Digital Dentistry as well, retainers which are partly manufactured using 3D printed models of the teeth. By using 3D printing, the retainer may improve the experience for the patient by using an intraoral scanner instead of taking a physical impression of the teeth [39]. The final step of vacuum-forming the retainer is the same as with the traditional method but by digitalising this process, simplicity, speed and accuracy of the manufacturing process may be obtained, as well as patient satisfaction [40]. This is due to that the patient does not have to take a physical impression which is considered to be not pleasant. The concluding part of producing a retainer which can be used for both teeth whitening as well as an alternative bracers, is that (after some preparations) the 3D model of the patient's teeth is placed onto a vacuum machine and a plastic sheet is heated and the lowered onto the the 3D model. This results in a plastic impression of the patient's teeth and the production of the whitener/ retainer is complete and ready for its use. For an example of a plastic retainer see Figure 3.7. Having scanned the teeth digitally, with a computer a preview of the final state of the teeth alignment is made for the patient and also each iteration step is calculated for the printed retainer to achieve the desired end result [32]. Having invisible retainer instead of bracers the patient has a much better experience, and avoid the hassle of added complexity when brushing her teeth (like having to use a special toothbrush).

Figure 3.7: One of the authors own plastic retainer, which may be used for applications such as teeth whitening and as alternative to bracers (photo taken by authors)

As for the case of alternative bracers (such as Invisalign), the physical retainer is replaced every two weeks and every six weeks a check-up is made to make sure that the teeth are adjusting according to plan. The retainer-type is in total typically used for one year [41]. See Figure 3.7 for an example.

Traditionally orthodontics have used metal in order to reposition missaligned teeth and not alternative methods such as Invisalign (plastic retainers with metal pressure points). Instead, small pieces of metal have been each cemented to a tooth and then connected by a metal strip with a varying degree of stiffness. In order to alter the position of the teeth, the metal gets tightened and replaced based on the progression of the teeth. Although the new technology could drastically improve the patients' experience compared to metal orthodontics, there are still rare cases where metal orthodontics are required. [42]

Night guards are used to protecting the teeth when there is a problem of teeth grinding during the time the patient is sleeping. These are possible to be 3D printed.

Indirect-bonding trays
Placing the nodes of the metal wire bracers is traditionally done one by one and takes some time to get correct. With AM an indirect-bonding tray may be manufactured helping position the braces connections correctly and quickly [43].

3.4.4 Digital dentures

Dentures may be done quick and accurate by printing them in two parts, one with gum colour and one with teeth colour and then glueing them together [43].

3.5 AM in similar fields

How is AM used in similar fields outside of dentistry? Could some knowledge or methods be transferred between these?

Brief research was made across all fields. A deeper search is limited within the medical field due to the characteristics of the (possible) AM usage is similar. AM used in the medical field is often uniquely adapted to each patient, this low volume and the high degree of individualisation aren't as common in other fields. Prototypes being the exception, which ranges across all fields without any specific AM technology or method used. AM is beneficial for low volume and high customisation due to its manufacturing methods.

3.5.1 Surgical operations

One big area for AM in the medical field is within surgeries, which could help save money and give better outcomes. AM are found in surgeon planning and training, implants, organs, and educating the patient. These are explained in more detail below.

3.5.1.1 Surgeon planning and training

In surgical operations every patient is unique, and by printing: visualisation and planning by the surgeon may be done for the specific patient and her affliction. It is possible to have the surgeon even do dry-tests [44]. Which is backed up by Dr Justin Ryan in an interview *"A doctor can look at and practice on a customised 3D printed model prior to surgery. Then we potentially have a better surgical outcome"* [45].

3.5.1.2 Surgical guides

During surgery different kind of printed guides may be used to increase the accuracy of the operation. For an example stereotactic platform, which is used for operations inside of the head [46]. This is the corresponding, or rather the family above, dental surgical guide instruments as stated in Section 3.4.2.

3.5.1.3 Customised implants

Even the implants may be done with AM with every implant uniquely fitted for the patient, and a porous structure may be printed which gives a good in-growth for human tissue. AM may be used for eg.: hip implants, finger implants, and spinal implants [46]. This may be linked to dental implants.

3.5.1.4 Biomanufacturing

Research is undergoing to create 3D-printed organs. The problems faced today is that donated organs don't have a perfect match and risks to be rejected by the

receiving body. There is also a shortage of organ donors [47]. By printing with the own patients' cells, it minimises the risks of rejection. One treatment today for burn victims is grafting skin from another place of the own body. One promising lead in biomanufacturing is 3D-printed skin which eliminated the problems of taking it from somewhere else [48].

3.5.1.5 Patient education

In order to give the patient a better understanding of the procedure, a printed model may be made uniquely for the patient. The dentist/doctor may thereafter in detail explain the steps of the procedure with visual aid which allows the patient to be more involved and understanding of the operation. A study has shown that for American hospitals that have invested in a 3D-printer 57 % have patient education as one of the uses of it [49].

3.5.2 Prostheses

Individually adapted prostheses have traditionally been expensive to manufacture. With AM these may now be made low-cost, especially in developing countries this have a big impact [45].

3.5.3 Hearing aids

The anatomical fitting of hearing aids is important because these are worn many hours each day and need to be comfortable and fit nicely for a good function. Due to every person have a different ear canals the hearing aid shell will need to accommodate this. With the help of AM, this may be done without long manual work as done previously [50]. Specialised hearing aid shells are the most similar product-wise to the possible AM dental crown, that may be read at 3.6.1.

3.5.4 Pharmacology

There are many persons in Sweden having to take daily or weekly pills and for some there it may be difficult and cumbersome to keep track of the different ones and having to take several at once. Usually, it is only a small percentage of the pill that has the active compound in it. With AM it is possible to create one pill consisting of different compartments with different doses and releasing time in the body, a so-called "polypill" [51].

3.6 Areas where AM could be implemented in dentistry

Possible areas to implement AM have been identified within the dentistry field. For both of the areas, work is in progress to make it feasible. Identified are dental crowns and dental implants.

3.6.1 Ceramic dental crowns

Ceramics is the material that dentistry want to move towards when manufacturing crowns (onlays, inlays, bridges, etc.) [52]. Using stereo-lithography some studies suggest that the trueness requirements are fulfilled, that is, the dimensions accurate enough [53] [54]. Some machine manufacturers present ceramic printing machines for "dental applications". Though after deeper research it is shown that the technology still is some time away. After contacting the machine manufacturers they are hesitant to provide samples and one says "we know the quality is not good enough yet (tolerance, colour, cost, turn-around time)". Talking with a lecturer from the dental fair Swedental, he believes the technology for commercial use to be about 6-8 years away [55].

3.6.2 Dental implants

Today, dental implants are made from long rods (primarily made out of titanium) which are cut, threaded and shaped into implants [56]. However, there is a possibility to instead 3D print the implants. In a three years follow-up study, it has been proven that titanium implants which have been 3D printed and fitted into jaw bone had successful results. 94.5 % of the 3D printed implants survived and 94.3 % of implant-crowns success rate [57]. It is also concluded in the article that the there is no need for post-treatments for the printed implant and that the rougher surface that appears from 3D printing actually is desired [57]. It should be noted however that these findings are based on a three years study and that there are uncertainties to the longevity and function of 3D printed implants on a longer perspective.

3.7 Dental market

The Swedish dental market can be divided into two branches, namely; Folktandvården and private dental studios. Folktandvården is governed by locally elected politicians on the county council level. Studios within Folktandvården are obligated to follow the decisions and directions which are taken by the politicians. In contrast, private dental studios have control over their own operations at their studio and not subjected to the same bureaucracy as Folktandvården, however, the same laws and regulations apply to both Folktandvården and private dentists.

Based on Privattandläkarnas annual report, the following data could be concluded:

The Swedish dental market has a total revenue of 26.7 billion SEK yearly, this includes both private dental studios as well as studio public healthcare studios. In total, there is 25 000 employed within dental healthcare in Sweden. 49 % of the total revenue comes from small dental studios which have revenue between $0 - 3$ million SEK per year. Studios which has a revenue above 9 million SEK yearly constitutes 9 % of the found studios in Privattandläkarnas annual report. This implies that the major part of existing dental studios is varying from small to medium in size and that there very few big players on the dental health care market. It is also

concluded in the report that it is the SME:s that are growing in market share. The two major dental health care providers who have had a large stable market share is Folktandvården (public dental care provider) with $\sim$ 30 % 2015 and Praktikertjänst (private dental care provider) with 26 % 2015 [58].

In Sweden there is currently about 1 600 private dental care providers (where the majority is SME), and roughly 880 public dental care providers. The public is often bigger. Apart from these primary dental studios, there are laboratories which produce (among other things) artificial crowns and bridges, it is about 540 dental laboratories in Sweden [59]. In a survey done by the paper TandTeknikern they found that the ongoing digitalisation increases the number of CAD/CAM products at the labs, and more 3D-printed jobs are done. Of the production 58 % are done with CAD/CAM and 42 % are done with the traditional methods [60].

3.7.1 Digital Dentistry market

The Digital Dentistry field is experiencing a solid and high growth rate, which opens up new markets for newly established companies. The global market of Digital Dentistry is expected to grow about 8.1 % annually (from 2016 to 2027) and Europe holds the largest market share of 42.2 % [6]. The 3D printing medical sector is growing at a rapid pace and the market seems to be expecting a huge upswing in the use of AM in the coming years. This claim is backup by SMEs annual medical report which specifically states that dental 3D printing is expected to grow by $39.7 billion by 2027 and the utilisation of AM within the medical field, in general, is expected to continue to grow [49].

As it is today, dental studios are faced with the decision whether to invest in an intraoral scanner or to continue using alginate for making impressions of the teeth. Since the cost of an intraoral scanner is seemingly high, an investment is not easily done. However, there are dentists who have transitioned and been very pleased with their purchase. In an article from Sree Roy, it became apparent that there are more benefits of purchasing an intraoral scanner and going digital, than simply potential cost savings. The dentists have experienced that there are fewer revisits (no need to take their impression again) with the scanning compared to using alginate, the active time consumption for two major stakeholders (patients and assistants) has gotten reduced and assistants no longer have to stay late at work to cast models and visit a postal office to ship them. Moreover, the dentists reported that the lead time of the orders was reduced, the patient care was improved (due to a more pleasant experience) and payment from medical insurances was paid faster [61].

3.7.2 Intraoral scanners on today's market

There are several manufacturers which produce intraoral scanners and in order to understand how this market landscape looks like, a comparison of the larger manufacturers, as well as alternative options have been made by the authors based on similar previous work done by others (see Table 3.1 and Table 3.2). The comparison

Table 3.1: Comparison and mapping of different intra oral scanners on the market (consolidation done by authors, information obtained from [62] and [60])

Intraoral scanners	3Shape	3M	Align Technologies Inc
Product(s):	TRIOS 3 Wireless, Pen Pod, TRIOS 3, Handle MOVE, TRIO 3 Mono Cart	3M™ True Definition Scanner, 78011 3M™ Mobile True Definition Scanner, 78032	iTero Element iTero Element 2 iTero Element Flex
Price? Licence?	**Trios 3**: ~ 320 000 SEK **Trios 3 Mono:** ~ 225 000 SEK ~15 000 - 20 000 SEK/annually	**Mobile:** ~185 000 SEK + tax. ~2000 SEK/month	**iTero Scanner:** ~ 195 000 SEK
Open source?	Yes (after Q4 2018 update)	Yes	Yes
Exporting format?	Exports . STL (after new update, previously .dcm)	Exports .STL	Exports .STL

Table 3.2: Comparison and mapping of different intraoral scanners on the market (consolidation done by authors, information obtained from [62] and [60])

Intraoral scanners	Straumann	Carestream	Sirona
Product(s):	Straumann CARES	Carestream 3600 (Ortho)	Sirona Omnicam
Price? Licence?	~ 160 000 SEK 13000 SEK/annually	~ 295 000 SEK	iTero: ~ 270 000 SEK , ~ 21 000 SEK/annually
Open source?	Yes	Yes	Yes
Exporting format?	Exports .STL	Exports .STL, .PLY	Exports .STL

is kept to a very few numbers of parameters since it was concluded that technical specifications don't necessarily say a lot about the end result. It is also difficult to compare technical specifications between different manufacturers since the terminology used is often specific for each manufacturer. Moreover, the purpose of this mapping was to highlight the general costs associated with purchasing an intraoral scanner and not to find the "best" scanner.

3.8 Other dental digitalisation areas

Further, than previously mentioned AM-related areas, there are more areas for dental studios to digitalise within. They will not be deeply researched in this report but isn't deemed so complicated and would give benefits to the consultancy company wanting to offer a complete service. Listed below and shortly described. Gathered from study visits and also some shorter research online [63].

1. Digital x-ray
    - Check if the old x-ray machine may be kept! It's the receiving end that is digital.

2. Digital camera
    - Makes the documentation for both Försäkringskassan and your patients easier. Includes the benefit of a digital archive (make sure to back up!)
3. Digital Journal system
    - Make sure to keep a good back-up system and avoid emailing journals to patients, they might go astray.
4. Social media
    - To be seen on social media such as Facebook, Twitter, Instagram, etc.
5. Digital payment system
    - The Swedish society at large is moving to be more cash-free.
6. Digital booking system
    - Instead of calling, patients may book, reschedule etc. via an online form.
7. Digital dentist visits
    - For visits not needed to meet physically were video and audio is enough.
8. Digital Smile Design
    - Together with an intraoral scanner the proposed design of the teeth modifications may be shown to the patient on a screen together with their live face. Making it possible for the patient to try it out and suggest changes when moving the head around.

4

Results

This chapter starts with description on how the project was conducted. Afterwards it continues with production methods and materials, the identified business opportunities, a little deeper look at stakeholders, description of the main service developed, results from the market survey, about the live test of the main service and lastly the environmental impact of digitalisation.

4.1 How the project was conducted

The thesis was an exploratory study which started with few limitations regarding scope, which during the thesis shifted in size and direction when finding areas of interest. The main starting aim was to evaluate the Digital Dentistry processes, possibly improve upon them, and find business opportunities applicable to a company similar to the thesis initiator. The thesis was carried out in cooperation with Hononga AB, dental studios and a dental laboratory where observations, interviews and investigation of the processes took place.

When developing products and services in the medical field special considerations needed to be made because the quality of treatment could have a huge impact on the individual. Tactfulness during study visits with real patients present was required, due to the vulnerable situation the patient is in during a dentist appointment. In order to have the important sustainability aspect of our recommendation, societal and ethical aspects were taken into account when giving our final discussion/recommendation.

Continuously throughout the thesis, documentation was made by using a number of digital documents that ultimately led to this thesis report. The documents used the most were: contact list, work diary, thoughts, meeting notes, weekly progress reports, weekly to-do lists, study visit documents. All documentation and data which were produced and collected during the thesis were accessible in a shared Google Drive folder. Within this folder, there were numerous sub-folders which simplified the process of finding the desired document/data. Examples of these sub-folders are "Market Survey", "Study Visits", "Weekly documents" and later on "Report writing".

4.2 Production methods and materials

[64] After discussion with dentists, a manufacturing company and experts within the field of AM, it was concluded manufacturing artificial dental crowns with AM in ceramics is not ready for implementation in today's dental field. The technology has years left until the end result is up to standard with comparable methods which exists today. The primary roadblock is the strength of the 3D printed dental crown which are far behind ceramic crowns which are milled from a block of material.
There are three big manufacturing methods for dental crowns done today: casting, milling and laser sintering (AM). With four big material groups: CoCr, Zirconia, Ti and gold. Where the usage of gold as a material, is shrinking and is usually casted. The state of practise material Zirconia, is milled, and CoCr is ... and is manufactured with AM.

In-house manufacturing of dental crowns
There is a interest among early adopting dentist to have more procedures made in-house, at the dental studio. An application field for this is to start having dental crowns made at the studio, this could enable the dentist to be able to offer one-day-visits for its patients. This implies that a patient wont need to wait a week or two for a new appointment in order to get the ceramic crown installed, which would be highly appreciated by the patient. A way of achieving this could be by having a 3D printer in the dental studio which prints the crown during the day while the patient is taking a tour in the city. However, there are practical roadblocks for implementing a 3D printer into today's dental studios. There's generally no need of having a dental labratory located in expensive facilities in the center of a city, as stated by Eduard Hryha: "Technicians don't need to be at Götaplatsen" [33]. Moreover, since AM crowns in Zirconia is not possible at this current state of time, there is the possibility of using a metal based material instead, Cobalt-Chrome. 3D printing CoCr is however not as simple as it might appear, below are reasons stated as to why AM of CoCr is not working for an in-house application at a dental studio [33]:

- CoCr powder is bought in large containers and by storing it for a long period of time, the powder degrades. Due to low (usually) low volume production in a dental studio, this makes it difficult to have a CoCr printer in-house
- The start-up time of a 3D printer capable of printing CoCr requires 1-2 hour(s) in settings and maintenance, both before and after the printing which makes it very time consuming for the dentist and thereby not economical
- In order to have a efficient manufacturing, the build plate of the 3D printed should be filled to full capacity. This implies that a dentist would need to wait until a couple of patients need a crown/bridge before starting the manufacturing. For small dental studios, this could mean weeks before the build plate is utilised at full capacity. which in practice would imply that it is not possible to achieve a one-day-visit which is wished for

However, there are advantages of using CoCr instead of a ceramic material such as Zirconia:

- Metal crowns are fast and cheap to produce, which therefor could make it more suitable an in-house dental studio application (rather than a printer which prints in Zirconia)
- It is possible to 3D print bridges in metal, while it is not possible in Zirconia
- Productivity wise, 3D printed metal crowns is faster to produce as compared to Zirconia

The comparison between milling and 3D-printing was primarily focusing on the material Zirconia since the trend within dentistry is to move away from metal based crowns and into ceramic based. Moreover, dentists wants to move away from adding a layer with porcelain on top of the Zirconia due to micro-cracks in the surface [65]. Which is possible for Zirconia crowns but not for the CoCr to fulfill the aesthetics requirements.

When comparing milling and AM the work-flow is similar. For comparison observe the work-flow for the manufacturing of an artificial crown in a dental lab including milling in Appendix B, Figure B.4. The difference is to replace the milling box with AM. Due to the work-flow being similar, a transition from the current way of working into the new, may be done fairly easy. However, it requires another level of technical knowledge as well as more time when starting up and closing down the machine. Further, with the choice of correct Zirconia composition, the porcelain step in the workflow might be able to be cut out, shortening the workflow chain.

As it is today, In-house production is not common for dental studios to have, instead of outsourcing to dental labs is the standard (see Appendix F). When it comes to deciding whether to have in-house or outsourced manufacturing, these three primary important considerations need to be taken into account:

- **The entry costs of manufacturing machines**
  The machines that are needed to produce products such as a crown or a bridge are very expensive and it would take many years to repay the investment, even for a large dental studio. The state of practice at dental labs today, the big investments involve purchasing a milling machine as well as a sintering machine. These machines vary in cost between $\sim$ 160 000 SEK up to 1 million SEK. A general guideline would be that a milling machine may be purchased for roughly 340 000 SEK and that it requires $340 - 520$ of uses of the milling machine to repay the investment of the machine. Moreover, a sintering machine is required to post-process the milled part. A sintering machine may be purchased for roughly 50 000 to 100 000 SEK
- **Space consuming**
  Another important aspect to consider for a dental studio is to evaluate whether there actually is space for having the required machines in-house. Not only might the required machine take up a large amount of space, but it could also require a separate room due to dust particles which is in conflict with the sanitised dental studio environment.

- **Need of time and care**
  Machines need care and maintenance, which allocates time that may be difficult to find for small dental studios (without hiring someone designated for the task).

4.2.1 Health and environment

Based on the performed survey and interviews, it can be concluded that the trend within dentistry is to transit towards Digital Dentistry and digital technology. This transition is favourable for the environment since it reduces the need for transportation of 3D casting models, since those now can be sent digitally directly to the dental lab. Further, it also reduces the need for packaging material which is used to protect the impression, for instance; cardboard and plastics.

AM manufactured (in metal) teeth should, in theory, be safe due to it being encapsulated by a ceramic layer and thereby is not in direct contact with the patient. Nickel-based chrome is being replaced with CoCr because it's considered safer. Although, it is worth mentioning that there is a risk of cracks and damages on the encapsulating ceramic layer which could lead to that the patient comes in direct contact with the metal. Direct contact with metal is deleterious for the patient and a factor which is worth considering. Based on this the preferred material of dental studios have shifted to using a Zirconia which is not deleterious if it were to break in the mouth, and thereby also more health friendly.

Google om Cobolt - dangerous to health? Environment aspects? Recycling? Rare/-Critical metals?

4.2.2 Recommendations

Some contact with a manufacturer of 3D-printers in the Netherlands was made. For them, the following is still lacking for manufacturing of dental crowns: tolerance, colour, cost, and turn-around time. Although there are a couple of studies claiming to have printed within high enough of tolerances, [53] and [54], an interview with a dentist from Umeå at the Swedental 2018 fair (Gothenburg) said commercial use of AM Zirconia crowns should be about $6 - 8$ years away. Further contact with machine manufacturer shows that despite what they write on the web-page sounds really promising it is still a long way to go for them.

The development of 3D-printing is going quickly but still, there is some time left before commercial printed artificial crowns are available. Our recommendations to the initiating company are therefore to focus on the broader Digital Dentistry with milling but keeping an eye on the AM development. When AM is proven enough, due to the similar work-flows, a transition from milling to AM should go moderately smoothly.

4.3 Business opportunities identified

Brainstorming were used to come up with interesting areas to pursue in the thesis. These were thereafter developed a bit and then analysed with SWOT. This collected data was then presented to the initiating company during the first gate of the thesis, see Appendix D. Together lacking areas were eliminated, although the authors had the final say. From this two business proposals were further developed. Bites2Bytes in more detail, and ScanVan to a less degree. One other area that survived the alimination was also Zirconia AM crowns, though because it was later found still lacking in several aspects so, instead it is presented in Section 4.2 and not further developed.

4.3.1 Bites2Bytes

This is the service that was developed the furthest and will also be the focus for the following market survey and discussion and final conclusions. Bites2Bytes offer a dental studio an opportunity to together with the consultantcy company perform digitalisation of their studio to a higher or lesser degree with the help of a workflow. See Section 4.5 for the details.

4.3.2 ScanVan

The idea of this business proposal is that since some dental studios only needs a digital solution once in a while (e.g. for a more complex case), they may order the service and the company will arrive in a van equipped with a mobile dental laboratory and are able to perform the requested tasks. Supporting this idea is the weight of the equipment needed for making a crown is no more than 100 kg (see list below). The laptop for the scanning device may also be used for the CAD and CAM. The unlisted material: brushes, liquids, material, dremel tool, UV-lamp, etc. is under 10 kg. By looking to the weigh aspect, therefor it may be concluded that it would be possible to transport it in a van without any problem.

- Scanning device (including laptop): < 10 kg
- Milling machine: 40 kg
- Sintering machine: 40 kg
- Other: < 10 kg

4.4 Stakeholders

Identified stakeholders with needs and wishes are listed below from a general point of view with the interaction between the actors. The needs have been investigated by the help of the method Business model canvas. This was done with the dental studio in focus. The canvas' may be seen in Appendix E. Looking at the importance and need of the stakeholders it may be concluded that patients and dentists are at a high importance for the drive of digitalisation, see Table 4.1. In the following

subsection the patients importance will be discussed a bit further.

- **Project initiator (Hononga AB)**
  Wishes to collect expertise knowledge about the field, and find possible business opportunities to, develop and position themselves on the Digital Dentistry market.

- **Dental studio personnel**
  Dental studios supply their customers, patients, with the value of oral health and oral aesthetics. They aim to have very long-lasting, sometimes decades-long, relationships with their customers. Communication channels used is in-person communication, phone (calls and SMS), email, and through their website. Key activities are routine check-ups to find complications early, and procedures to maintain or heighten oral health and aesthetics. This is done with the key resources: studio, dental machines, expandables, dentists and personnel. Key partners to the studios are therefore dental labs, suppliers and dental machine manufacturers. All of this gives the costs: rent, salaries, expandables, machines, and buying services from dental labs. The revenue streams to cover this are: patients directly but also society (in form of the government) that sees benefits in having a healthy population.

  Digital Dentistry may affect the dental studio by decreasing the time taken for each patient and needing less expensive products which increases the profit margins. Further, less revisits due to lacking quality.

- **Dental laboratory personnel**
  Dental laboratories do the key activities of designing and manufacturing (the value proposition of) dental products which is shipped (channel) to their customers, dental studios. They want to have a close relationship with the customer due to the high demand for quality, they need to earn their trust. Key resources of the company are their lab-technicians and manufacturing machines which bring us to the key partners: machine manufacturers and suppliers. All of this adds up to the cost structure of salaries, machines, rent, shipping fees, licences, rent and expendables. Which needs to be covered by each product sold.

  Dental laboratories might be affected by Digital Dentistry by the decrease of time and manufacturing cost for each order. As for the personnel, it is crucial for the dental technicians that the model of the patients' oral cavity are of good quality. With digital data much quicker feedback might get done.

- **Suppliers (of expendable material)**
  Here Suppliers (sales) of expendable material could be aiming at Customer segments: Dental Laboratories, Dental studios, or both. The value they offer is to gather widely different material needed for a field in one place, and because they are buying in bulk they could offer lower prices. They want

to have a good relationship with their customer and being able to guarantee quality is very important. Key partners are sub-suppliers, key activities are buying and selling of materials which they do with their key resources: expertise knowledge, logistics and sellers. Their cost structure is mainly buying material, paying salaries to personnel, rent of storage and transport. Due to less waste and thereby smaller volume of sales they might be affected by Digital Dentistry. Sales to the dental studio will be affected hugely during a digitalisation because the following is not needed anymore: impression trays, impression mass, and plaster.

- **Manufacturers and maintenance**
  Macine manufacturers with their suppliers (key partners) manufacture and gives support (key activities) with their expertise and recognised brand (key resources) to give the value of machines and support to machines to their long-lasting customers (dental laboratories and dental studios) via a website, phone, and visits. They sales machines to cover the cost structure of manufacturing, development and salaries (including support).

  Manufacturing and supporting hardware as well as software. Digital Dentistry might affect them with different kind of machines and more focus on software support.

- **Patients**
  Patients wants quick and painless procedures with as few visits and complications as possible to an affordable price. Since it is the patients that are directly affected by quality and prices, it is crucial to listen to persons who have undertaken the state of the art as well as the state of practice methods. It was concluded that digital technology gave a value creationg for the patients, the technology enabled smoother and an a more pleasant experience. This is the main driver for a studio to change, the increased value for the patient. Without the patients approval or need of changes, the studios risk loosing patients. Also see Section 4.4.1.

- **Society**
  The society as a whole benefit from a healthy population. In this area long lasting and faster solutions to dental problems with few revisits are attractive, so patients aren't kept from the workforce. The environment burden should be minimised (chemicals used, energy used, material type, material consumption, transports, etc.).

4.4.1 Patients - Drivers of change

By the use of the Customer Journey Map (see Appendix C) it was shown that there is one particular step in the process, installation of artificial crown, that may be highly benefited by transiting into a digital solution. It was shown that patients that were

Table 4.1: Table of Stakeholders with importance of digitalisation and their needs

Stakeholder	**Importance** Critical = 3 Very important = 2 Somewhat important = 1	**Needs**
Patient	3	Pleasant experience
Dental studio personnel	1	Fast accurate modelling Simple to use
Dental lab personnel	2	High quality models
Machine manufacturers	2	Growing market New technologies
Suppliers	3	Stable material sales

subjected to using an intraoral scanner felt little to no discomfort while patients whom had physical impression taken felt a great deal of discomfort. It is concluded from the map that the customer (patient) drives the change for the dental studio (there is a wish from the patient that the dentist has a digital solution). In contrast for the dentist the experience is approximately similar both in procedure and cost. From this wish by the patient, a need of the dentist emerges and translates into a market for companies which develops digital solutions, this indicates that there is a a potential good market for offering a service which helps in this transition which is what is suggested in Section 4.5. So in conclusion, the main reason for a dental studio to change and transit to digital technology is to have a need by the customer of a swifter and more pleasant experience compared to the alternative method. Other aspects such as good investment or smoother daily operation is secondary in contrast to the patient's wishes and needs.

4.5 Bites2Bytes - Giving dental studios support to digitalise

A procedure how a consultantcy firm may help a dental studio to digitalise is described. The workflow is presented in Figure 4.1.

4.5.1 Methods for service

To make a change at a dental studio, methods used for change in Project Management may be appropriate. The Double Diamond method is used to set up the project with the workflow (Figure 4.1) which is also using the Stage-Gate method. For all the four stages SWOT is used to identify the properties. During the third stage, a change management plan is set up [66]. During this stage, some extra focus is put on Kotter's step 2 to get the whole team at the dentist office on board and noticed. In general, detailed planning are made here, listing which persons and companies that are needed to be involved are stated. Return on investment calculations are also being made in this part of the service, which will allow the dentist to see

when and if the investment pays off, and also how big the investment for their studio is. Gantt is used to visualise, both for the company and for the dental studio, the change plan. Here they are able to see when their education is planned and when machines are implemented and so forth.

4.5.2 Starting the relation

The first challenge, before the initiation of the service, is to identify dental studios that are interested in making a transition to digital methods. This could be done by methods that are listed below. To get a good reputation that spreads through the field, and the studios initiating contact, would be ideal.

- Company website (searchable)
- Ads in (dental) papers
- Word of mouth
- Email/call/visit studios
- Offer free first consultation (ca. 0.5 hours)
- Cooperation with dental machine manufacturers (recommendation from these)

4.5.3 The work-flow of change

After having identified the potential customer the first stage begins, which is also the Discover phase of the Double Diamond method. »The first consultation« During the first interaction, it is important to be knowledgeable and professional in order to create trust. The hardest part (in the beginning) is probably making the dentist trust you, especially when the consultancy company is a newly founded company in a new field for the employees. The purpose of the first consultation, except for building trust is to probe and see why the customer wants to digitalise, how much and what they expect from it. Getting a feeling of it all. In the end, a suggestion should be made of a deeper analysis (or not) made by the consultancy company. The studio might want to have a longer thinking time.

When the first consultation is done approval/disapproval to continue working is made by the dentist. If approved, the dentist agrees to pay for the deeper analysis that will investigate all the possible paths or some of them. Investigation in stage 2, the define phase in Double Diamond, starts which solution is best for the particular studio. First, the consultancy company needs to gather data about: number of crowns, bridges and implants ordered yearly, as well as current costs and incomes. After this, return on investment calculations may be made. Factors such as physical space in the studio and the level of previous knowledge of the dentist within the digitalisation area.

The consultancy company presents suggestions and together with the studio they accept one, or more, of the suggestions and make detailed plans, this is also worked out together with communication with the rest of the employees in the studio to

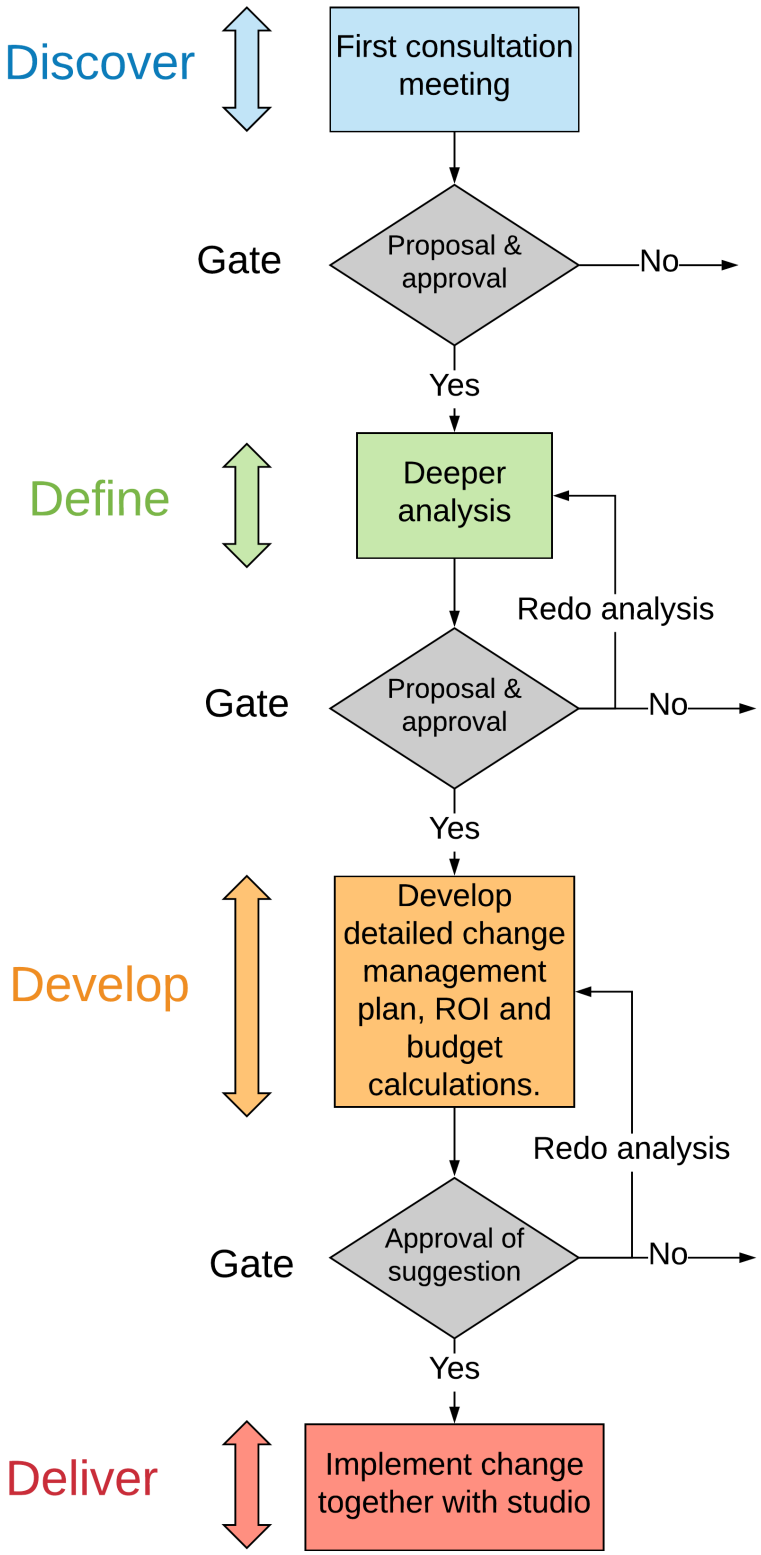

Figure 4.1: Process flow of the digitalisation service Bites2Bytes (illustration and process made by authors, inspired to some degree by methods from [18])

take them on board and make them a part of the process. That is, Kotter 2.

After the approval of the Develop phase, the next phase begins.

The Deliver phase, stage 4 may be divided into 3 steps. This is when the changes are made together with the studio. In focus for this is Kotter's step 5, 6, 7.

Step 1 - Instructions and support during the investment phase
Could do everything (which is approved beforehand with a budget) and let the dental studio just pay the bills

Step 2 - Installations and education during the transition phase
Installations outside of operating hours is favourable in order to minimise the disturbances for the dental studio. Further, creation of education material and in person support the first time the studios tries out the equipment.

Step 3 - Support and maintenance during the operation phase
After the transition, it is important to offer continuous support, which can be offered both remotely and by visiting the studio. By having a close cooperation with the manufacturers and by representing multiple studios, competitive prices can be offered due to the scale of economy.

At the end after the project is completed, an evaluation should be made. Make use of step 6 of the change management plan. This is very valuable for future cases. A repertoire of different dental studios may be built up and greatly simplify future work, and give a more accurate cost prediction early on for dental studios. See the Estimating tool "As ... but ... s" [18], which describes more similar projects with small variations may be done as *painting by numbers*.

4.5.4 Governmental monetary support for digitalisation

Small businesses looking to digitalise may have checks to collect from the government. For example, the Scania region (Skåne) offers businesses which fulfil some criteria, a check of up to 250 000 SEK. This is an initiative to support a more digitalised world, the checks which may be applied for is called *Digitaliseringscheckar* [67]. This might be something that is the final straw that convinces the company to do a digitalisation together with the consultantcy company.

4.6 Market Survey

To confirm the choice of business opportunities, to further develop these, and also to acquire data about how the dental market looks like, a market survey was created. The survey was sent out to an estimated 800 respondents and from these, in some cases, the email was forwarded to more respondents which makes it difficult to say an exact number that has been reached. In total, there were 160 respondents who responded to the survey. See Appendix F for the results from the survey. From the

data the following results could be shown:

1. A majority of the respondents were representing the private sector (55.6 % vs 35 % public and 9.4 % others)
2. 70.9 % would like to transit their studio into using digital scanning technology.
3. The reason most studios haven't made the transition yet was due to: "Big investment/expensive/not paying off" and "Looking into/about to implement it" (meaning that some already were in the process of digitalising).
4. The majority of those who use impression technology today would not like to have in-house production of artificial crowns and bridges (79.5 % said no and 20.5 % said they would)

5. The idea which later lead to the development of the "Bites2Bytes" service was included in the survey, in the form of asking if there was a intrest in a third party company to provide with consultation within digital dentistry. 18.1% of the respondents were intrested in such a service.

It was pointed out for the public sector that the individual dentist and not even clinic chairman are making decisions regarding digitalisation. Instead, these types of decisions are made at a regional basis, which is to some extent dependent on politics [68]. This concern about half of the dentists in Sweden [69]. Which is why the authors recommended that the initiating company should focus on the private sector and not the public sector.

4.6.1 Statistical significance

In 2010, 7 528 dentist was operating in Sweden. 4 070 in the public sector and 3 458 in the private sector [69]. The questionnaire was sent out to circa 800 receivers, which in some cases were spread further by these. The sample size of the respondents was: 160. Which with a 90 % confidence gives a margin of error of about $6 - 7$ % (if randomly selected among the 7 528 dentists). The aim of the market survey was to look for the general opinion of the dental studios and business opportunities at large, and therefore a low certain limit was accepted.

4.6.2 Error sources

The market survey is subjected to some degree of bias. Due to the goal of looking at the opinions at large, it shouldn't affect the result to a too large degree, but it is worth to keep in mind.

The first source of error is **inviting respondents**. Most of the respondents have been reached by searching after dentists online and then contacting their email-address if they had any (worth to note is that many dentists with a website just states a phone-number, and/or maybe a contact form). Because the respondents already have this digital aid they may be more open to further digitalisation. Further when choosing to respond to a questionnaire **biased non-response** may occur. In this case, dentists choosing to answer are probably more interested in Digital tech-

nology than dentists that choose not to do it. One more error source is **unclearness**, questions being interpreted wrongly. In order to not scare away too many respondents, especially busy dentists, the questionnaire was designed to be quick to fill in. This made the aim of the questions to be brief and informative, which may have made some questions possible to misinterpret. **Target group** of the market survey was dentists. Though this wasn't stated clearly anywhere and in some cases, other persons, such as sectional heads, have filled in the form. One questions, in the beginning, could have asked what profession the respondent have.

4.7 Live test of the digitalisation service Bites2Bytes

In the market survey it was possible for the respondees to leave their email address if they were interested in being contacted if the service would come into realisation by the consultantcy company. Some were contacted and one of these agreed to perform the initiating step to further analyse the service. Due to time restrictions (being close to winter holidays), the gathering of the first information was done via email. A form with required information was sent over. It proved to be difficult to collect necessary information. A conclusion was made that a meeting face to face as first contact is easier and better (as for the quality of the data, and building trust). Preferably the meeting should be conducted at the dental studio so the consultants are able to easier get a feel for the status of the studio and that the dentist may get a better understanding of what the service might include. The studio being part of the first test, gave response of the service as positive. There was a genuine interest of knowing more about digitalisation, and the service appeared to be a welcome compliment to the digitalisation area for dentists. This indicates that there is a need by dentists for a service of this kind.

4.8 Digitalisation and the environment

How will digitalisation of a dental studio affect the environment?

Regarding environmental aspects, there seem to have benefits with Digital Dentistry with fewer transports and less material used when implementing digital models. By not having to ship physical models across the country, there is a positive effect of reduced $C0_2$ emmisions, since the model may be sent digitally there is no need of transportation. By reducing the number of transportations, and thereby $C0_2$ emmisions, the dentistry market have the opportunity to help reduce the effect of climate change. Further, by having a intraoral scanner, there is no need to use alignate or silicon material to take the impression of the patient. Plaster, and the plastic/metal spoons are also avoided. This leads to less usage of materials and reduced materials waste, which is beneficial in order to reduce the environmental impact. Another part is eliminating having to build storage rooms for the physical models which have an environmental impact.

However, it should be noted that the new machines and new materials which are being used in the digital processes needs to be analysed in detail in order conclude the effect on the environment.

To highlight both the positives and the negatives with transferring to a digital solution by purchasing an intraoral scanner, the lists below have been derived:

Positive

- Removes the need of impression mass, plaster, plastic/metallic 'spoons'
- Removes need of physical storage
- By sending digital files to the dental lab. the transport of physical objects to the dental lab is eliminated
- Material savings

Negative

- Greater initial environmental impact
- Fast scanner development (in the beginning) makes it necessary to upgrade often to keep up with technology progress

5
Discussion

Looking at Digital Dentistry broadly with the help of the iron triangle [18] it shows that at the beginning of the implementation an increase in quality and decrease in time (when working properly) is earned for the price of increased cost. After the initial payments in the long run time, however, the cost will be saved by the improvements on the to other factors and will create a better service on all aspects.

Further, in the discussion environmental aspect will be looked at, the Research questions will be answered, what could have been done better, error sources in the market survey, the recommendations for consultancy companies in the field, and lastly what value the thesis hold.

5.1 Environmental aspects of digitalisation

Without going in too much details of the environmental impact by specific parts in the work process, it may easily be understood that moderately use of the scanning device which eliminates the use of impression mass and plaster, transport of physical models to the dental lab, and physical storage of models, will soon outweigh the negative impact of the manufacturing of the electronic device. Further, with other uses of digital equipment the x-ray may be used with a lower dosage of radiation, the improved accuracy of digital dentistry, in general, will most likely result in fewer revisits and remaking of dental products.

5.2 Revisiting the questions

Q1. When will AM of Zirconia crowns be commercially available?
A direct answer from a dentist at Swedental 2018 gave the prognosis of about $6-8$ years [55]. Even though articles hinting about a closer time frame the big time span stated was further supported by machine manufacturers contacted, which despite their optimistic websites admitted being far away from having a commercial product.

Q1.A. For in-house production in a dental studio, is AM or milling better?
For this comparison manufacturing of Zirconia was chosen. AM of dental crowns are already possible with laser sintering, this is due to investment cost, size and environment not thought to be a good match for a dental studio. Comparing the two methods shows they are very similar, see the workflows in Appendix B. Right now AM of Zirconia isn't possible but it seems to be the more attractive option due

to noise level and particles created. Because of the similar work-flows, it is easy to make a transfer to AM from milling with just replacing that particular machine, with some other smaller changes.

Q2. Why are not more dental studios digitalised?
There are many reasons, which are also listed in the results from the Market Survey, although the main reason is likely due to it being a fairly new technology and dentists are waiting a bit to see what positive and negative aspects a digitalisation may give. Some are also waiting with buying equipment because the development is fast which could make an early purchase obsolete after a few years. When the technique is not working correctly it may give big consequences and remove the profit previously created quick. Having the intraoral scanner as main option and the old method as a backup could be one solution for dentists who wishes to transit.

- Where is AM used, or may be used, in Digital Dentistry?

There are multiple areas within Digital Dentistry which use or has a potential of using AM, examples of these are: artificial crowns, surgical guides, bracers/retainers, and digital dentures. For a further explanation of this question, see Section 3.4.

- Why do dental studios want to become digitised?

Some of the benefits to this question were found from the Market survey by studios who have already digitised. It's a multiple choice and in order of number answers these are: More comfortable for the patient (49 %), want to be at the cutting edge of technology (47 %), in the end gives higher quality (36 %), more stable - fewer errors (30 %), faster process than taking impression (27 %), in the long run more economical (21 %). For the entire answer to this question, see the attached responses from the market survey in Section F.

- What roadblocks are there?

- What do the dental studios need help with?

These two sub-questions the authors chose to answer together because from the point of view of the dental studios are the same. There doesn't seem to be any specific roadblocks. For AM of Zirconia crowns, getting it close enough within all the different needed tolerances seems challenging but possible to solve in time. There is also currently an issue with the strength of 3D printed Zirconia crowns, in order to up to standard with milled crowns, however, this area is constantly improving. The slowness of adaption seems rather be linked with the trust that dentists have to the new technique and the return of investment (since it is a large investment to transit from current method to digital method). Multiple answer question from the Market Survey captured some concerns: It's too expensive (39 %), Problems with the quality of the digital process (8 %). They would want help with: education of the new technique (33 %), more knowledge of what products are on the market

(25 %), economical calculations (22 %), help with transit to new work-flows (14 %). Note: many answered they were already in the progress to digitalise which might be the reason the percentages are low because it captures everyone who answered (from the non-digitalised section of the respondents).

5.3 Areas of improvement

For a better thesis more prioritisation, with more time used, could have been put on validating the proposed business case with a more extensive live test. More time was not used due to it being an exploratory study the end result was not known and late changes were made when new information surfaced.

At first, the manufacturing of an AM ceramic crown was sought after as a test of how far the technique had come. A shift to test the business live was made due to AM manufacturers not wanting to show how far they had come with their printing regarding crowns which left our last step with less time than the authors originally planned for. Although with the small test made and the questionnaire sent out, shows that there is a market to be further explored for a consultancy company.

5.3.1 Error sources in Market Survey

To counter the error sources in the Market Survey the following could have been done. The error source is stated and underneath countermeasures are described.

Invitation of respondents
Contact could have been made by more means than sending emails to studios found online, e.g. filling in a contact form, calling, or sending physical mail.

Biased non-response
In could have been made an option which allowed invited respondents to say that they were not interested in participating in the survey, an "I don't want to be a part of the survey" option or similar. This way it would have enabled an understanding of the true response rate and what the proportion of possible biased selected respondents there may be in the survey. By simply having a first, stating question whether the respondent wishes to participate or not (and by possibly adding a follow-up question as to why not), more knowledge about the respondents could be gained and the biased error source further explained.

Unclearness
The Market Survey could have been tried out by sending it to some dental studios, being further modified, tried out again etc. in many iterations to further making it clear and inclusive. This was just done in one iteration with some dental studios due to timing.

Target group
It could have been made more clear that the form was intended for dentists. One

question, in the beginning, could have been added to categorise which group the respondent belongs to (dentist, nurse, etc.).

5.4 Recommendations to consultancy companies

The following recommendations are aimed at consultancy companies wanting to offer the service, or a similar service, akin to Bites2Bytes.

- Focus on the private dental sector

The recommendation to focus on the private sector is given because the dental studios belonging to the public sector "Folktandvården" does not have the authority to make decisions regarding digitalisation of the studio. These decisions are instead made higher up and they make their own research and negotiates with the manufacturing companies due to the high volume of purchases.

- Wait with, but keep an eye on, AM crowns in Zirconia

$6 - 8$ years are the expected waiting period, although this might change rapidly. That is why it's good to keep an eye on the development to quickly gaining knowledge the dental studios look for after launch.

- Offer support for a broad digitalisation of the studio

Don't focus on just AM. It is suspected to be a too narrow field. To gain trust from the dentist a broader knowledge-base is needed. The other digitalisation areas are deemed not so complicated and could tie together a whole package service. See Chapter 3.8. Basic dentist knowledge is also important to have when working in the field. Doing study visits to both clinics and labs is deemed necessary to really be able to visualise the work routines and the working environment.

5.4.1 Pros and cons with Bites2Bytes

In order to be objective to the service that has been derived from the thesis, pros and cons of the service have been put together:

Pros

- A desired service (based on the market survey, see Appendix F.
- Service is easy to understand for the customer, is a straight forward approach
- It requires few/no major investments, it is a knowledge-based service

Cons

- Easy for competitors to copy the service

5.4.2 Development of market

At the moment it looks like it's a good opportunity to join the battle. As said Digital Dentistry is expected to grow 8 % annually until 2027 and AM to further develop which make it possible to use it in new areas in the dentistry field.

5.5 Value of the thesis

The thesis is valuable mainly for consultancy firms aiming to begin in the Digital Dentistry field. It's also of some value for studios looking to digitalise. This because of the thesis collected facts and Market Survey. They may after reading use their own judgement for the continuation of their business. Further, the thesis has educational value for authors who wish to do research in the area of Digital Dentistry. It could also be used as a form for doing a similar study in another similar field. The market survey is valuable when looking at the state of dentistry in Sweden.
Looking at Digital Dentistry broadly with the help of the iron triangle it shows that at the beginning of the implementation an increase in quality and decrease in time (when working properly) is earned for the price of increased cost. After the initial payments in the long run time, however, the cost will be saved by the improvements on the to other factors and will create a better service on all aspects.

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Q1. When will AM of Zirconia crowns be commercially available?
A direct answer from a dentist at Swedental 2018 gave the prognosis of about $6-8$ years. Even though articles hinting about a closer time frame the big time span stated was further supported by machine manufacturers contacted, which despite their optimistic websites admitted being far away from having a commercial product. In a fast evolving field such as AM, this could, however, change quickly. A professor at Stockholms University working in the area of AM of Zirconia within the medical field is at the writing moment behaving very secretly about this.

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The main reason is probably due to it being a rather new technique and dentists waiting a bit to see what positive and negative aspects a digitalisation may give. Also waiting a bit with buying equipment because the development is fast here which could make an early purchase obsolete after a few years. When the technique is not working correctly it may give big consequences and remove the profit previously created quick. Having the intraoral scanner as main and the old method as a backup could be one solution.

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6
Conclusions

The following conclusions and recommendations are offered to the initiating company:

1. The market is ready, right now is a good opportunity to start
2. Focus on the private dental sector
3. Wait with, but keep an eye on, AM crowns in Zirconia

AM is a good match for Digital Dentistry. Nothing strongly against AM have been found. Though some development is taking longer than expected by some actors. The results show that directly 3D-printing dental crowns are not ready yet. The authors instead advise the initiating company to start out as a general Digital Dentistry 'consultant' within the Digital Dentistry market but to keep an eye on and creating a connection with actors that is developing the 3D-printing equipment for dental uses. Now should be a good time to start cooperating with manufacturers in order to "be early on the ball".

6.1 Future Work

The service Bites2Bytes needs to be developed further. It is recommended to do this either with communication with dental studios and labs or as a real live test where the customer might understand it will take some time to have the implementation. It's of importance to nurture a good brand that dentists will learn to trust and may spread in the dental community.

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A

Gantt schedule

The Gantt schedule describes the planning of the project. A living document that evolved during the project and this is the final version. The schedule is divided into two figures to be able to have it detailed enough, part one in Figure A.1 and part two in Figure A.2. The graphics have been created in Office PowerPoint.

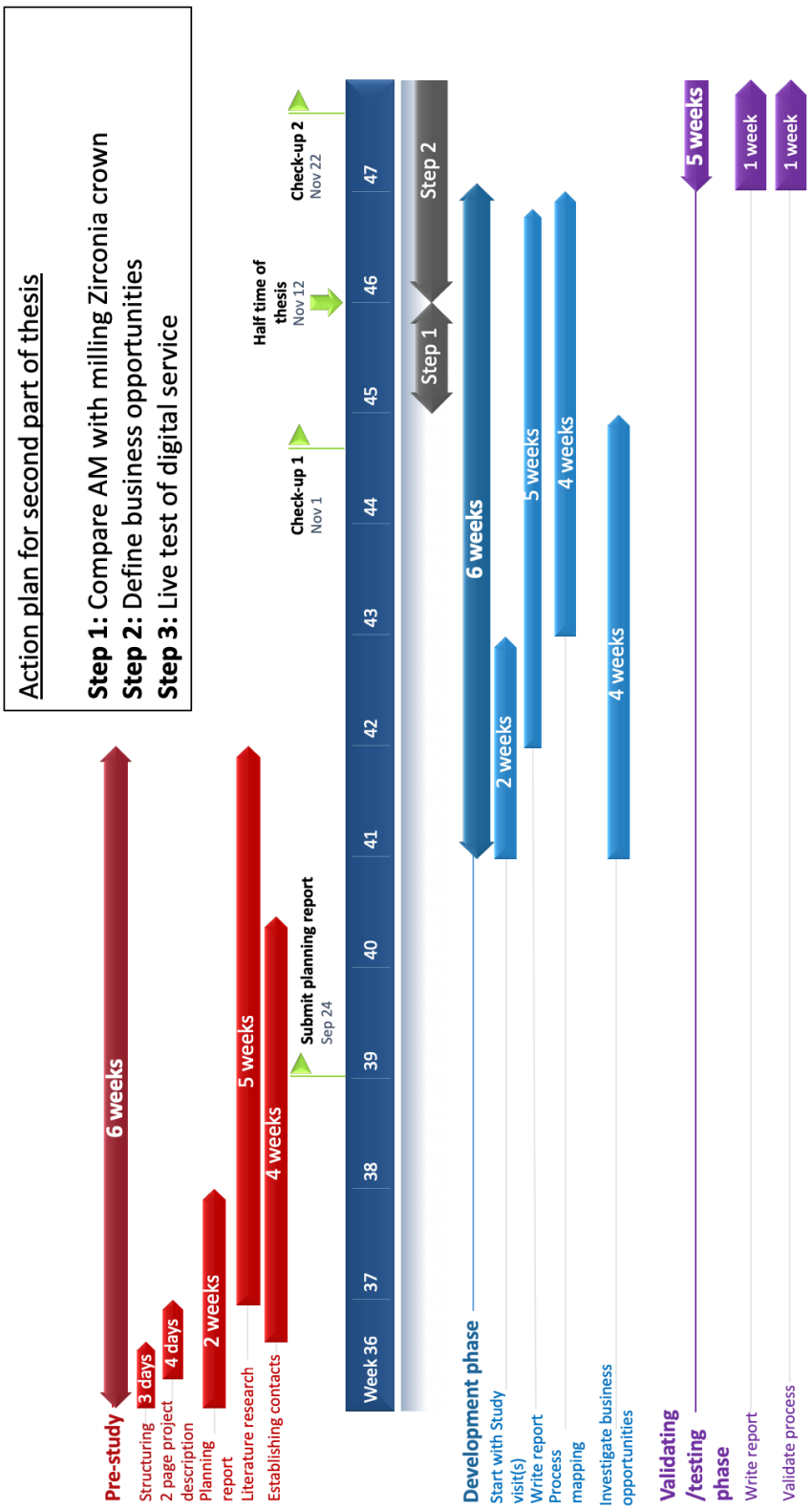


Figure A.1: Gantt schedule illustrating the planning of the project, part 1 of 2

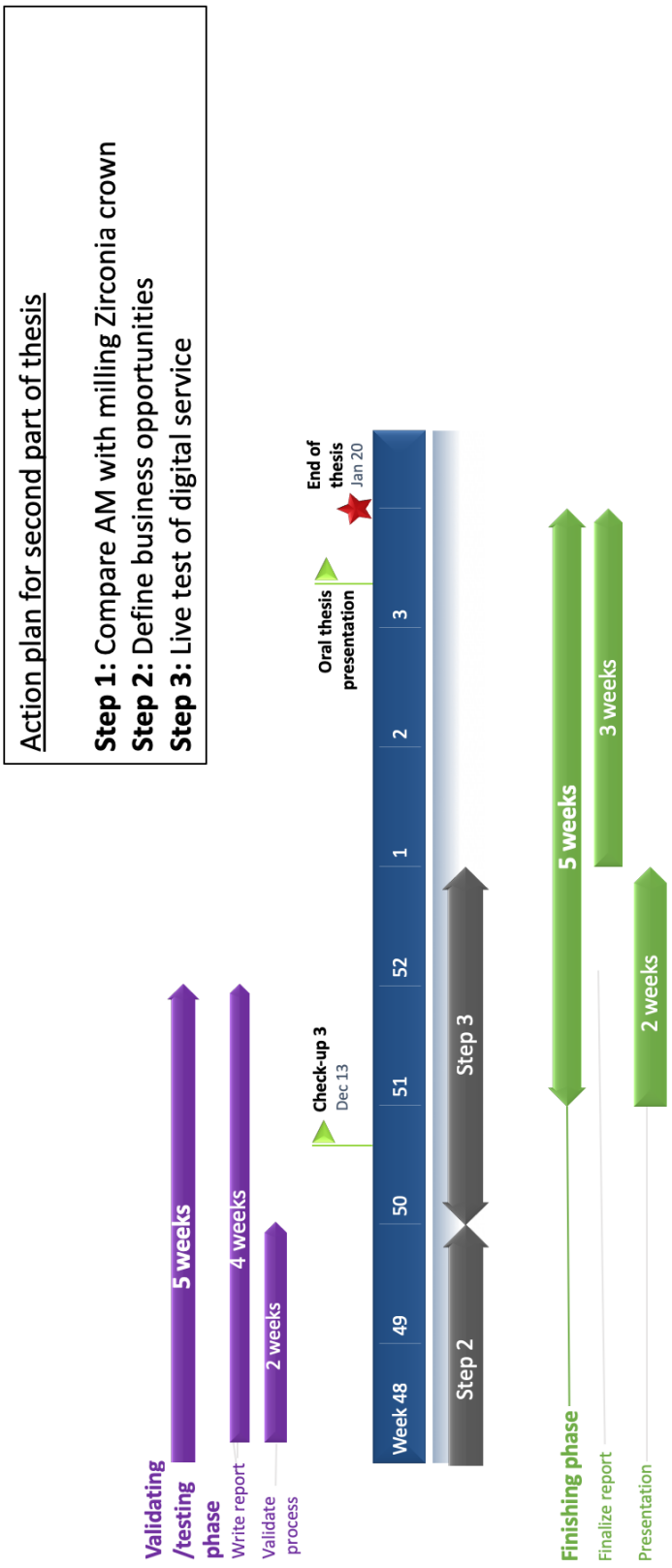


Figure A.2: Gantt schedule illustrating the planning of the project, part 2 of 2

B

Workflows

Here are the workflows collected. It shows the flows of material and patients. Arrows from underneath indicate tools used and arrows from the side indicated the flow of the "products". The data were collected from study visits at dental studios and a dental lab.

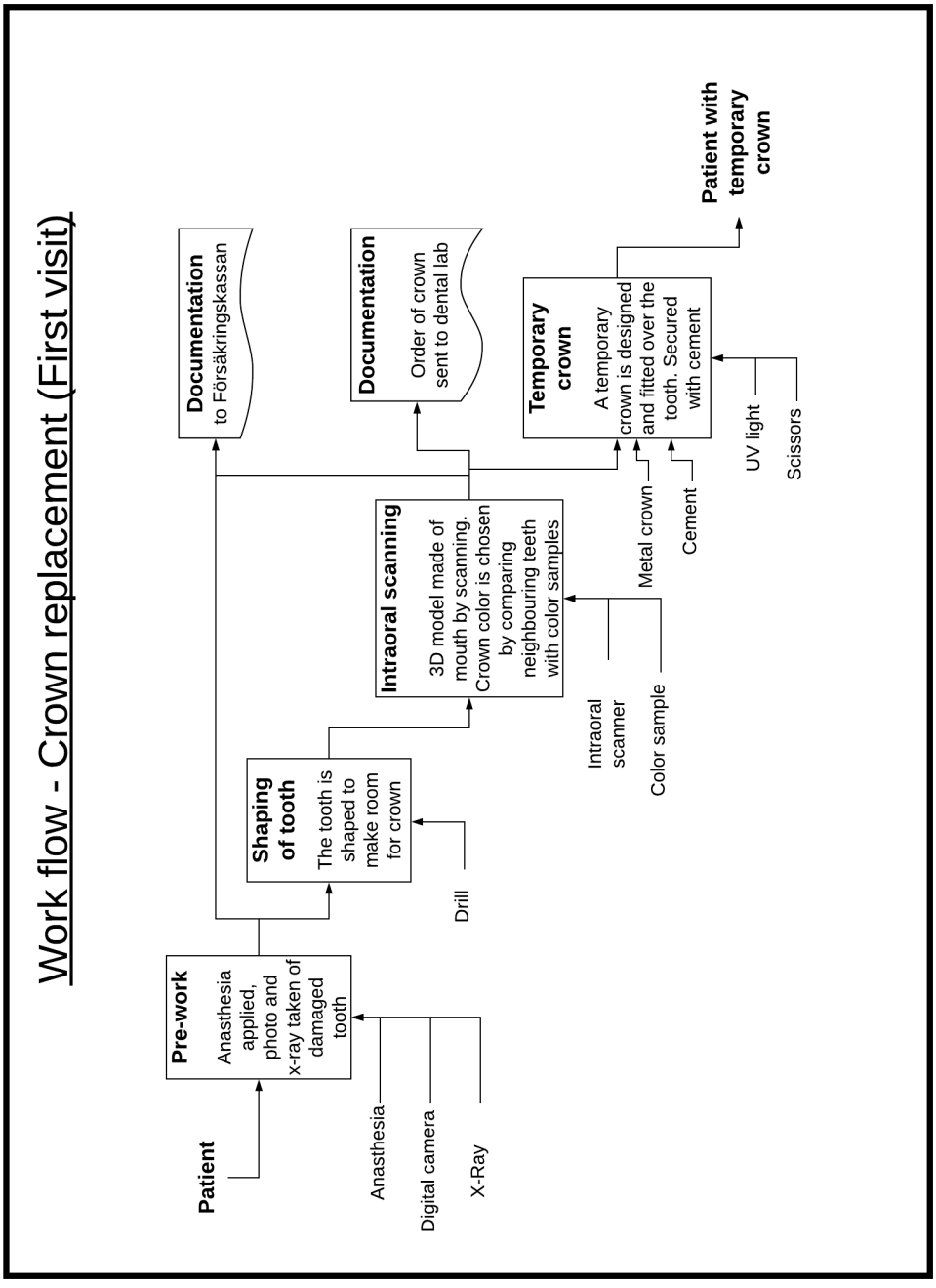


Figure B.1: IDf0 flowchart of artificial crown placement using Digital Dentistry - first visit

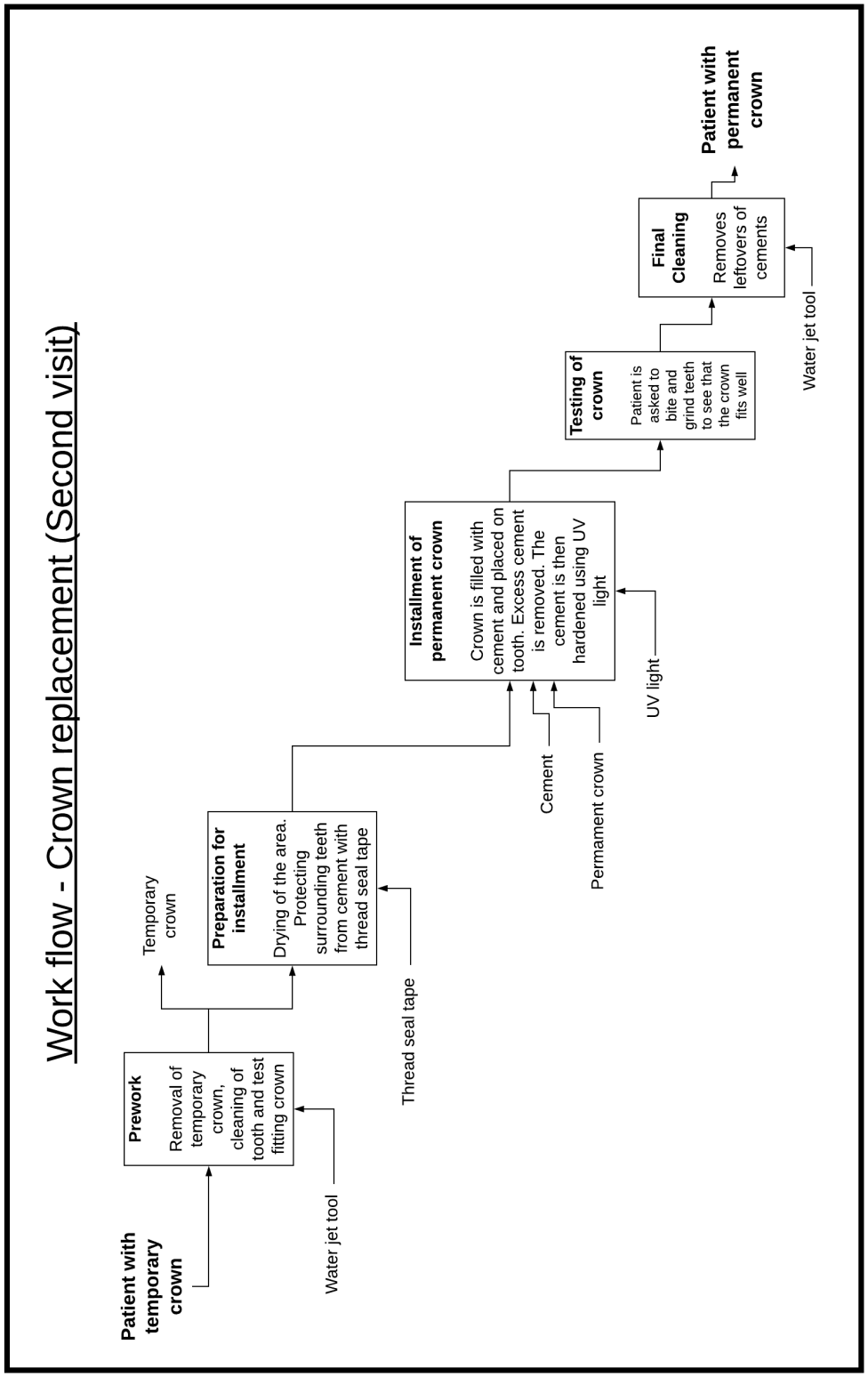


Figure B.2: Idf0 flowchart of artificial crown placement using Digital Dentistry - second visit.

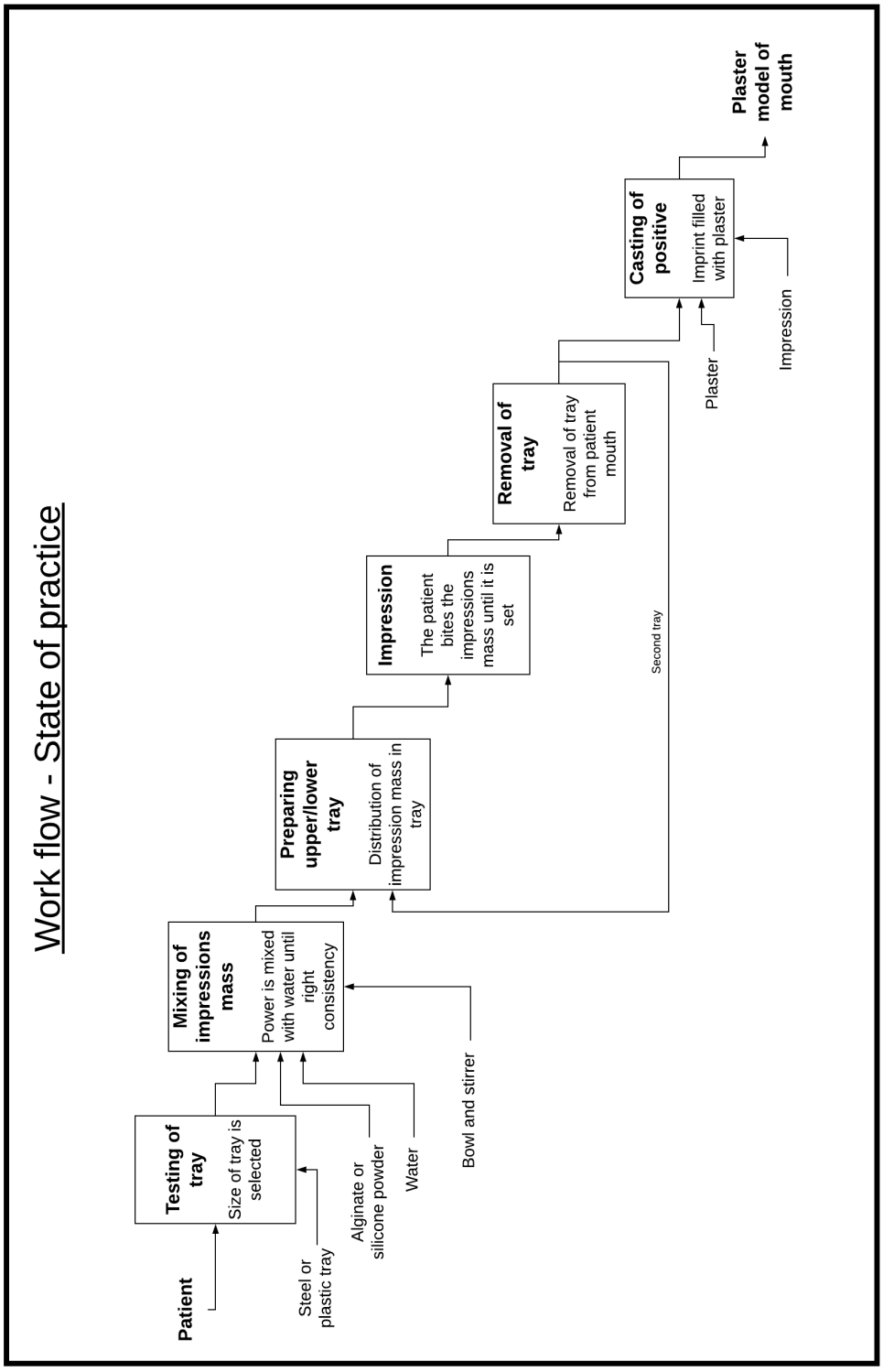


Figure B.3: Idf0 flowchart of making a model out of the oral cavity at a dental studio state of practice, upper or lower impression

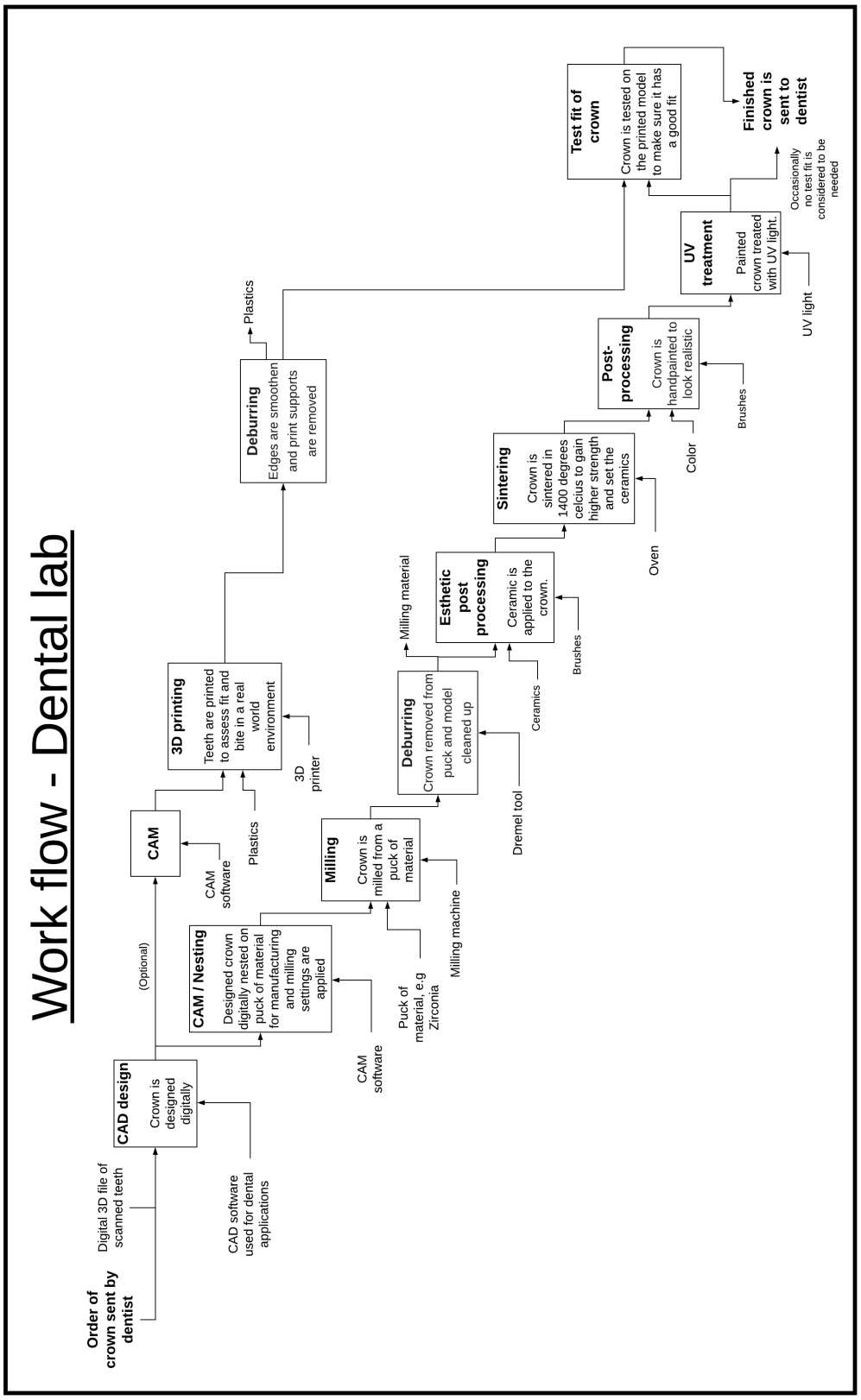


Figure B.4: Idf0 flowchart of the process of creating a crown at a dental laboratory

C

Customer experience

The customer experience is illustrated as a journey map of a patient undertaking a crown replacement process. The journey map is based on study visits and not for a single patient. It is to be seen as an illustration rather than a precise graph.

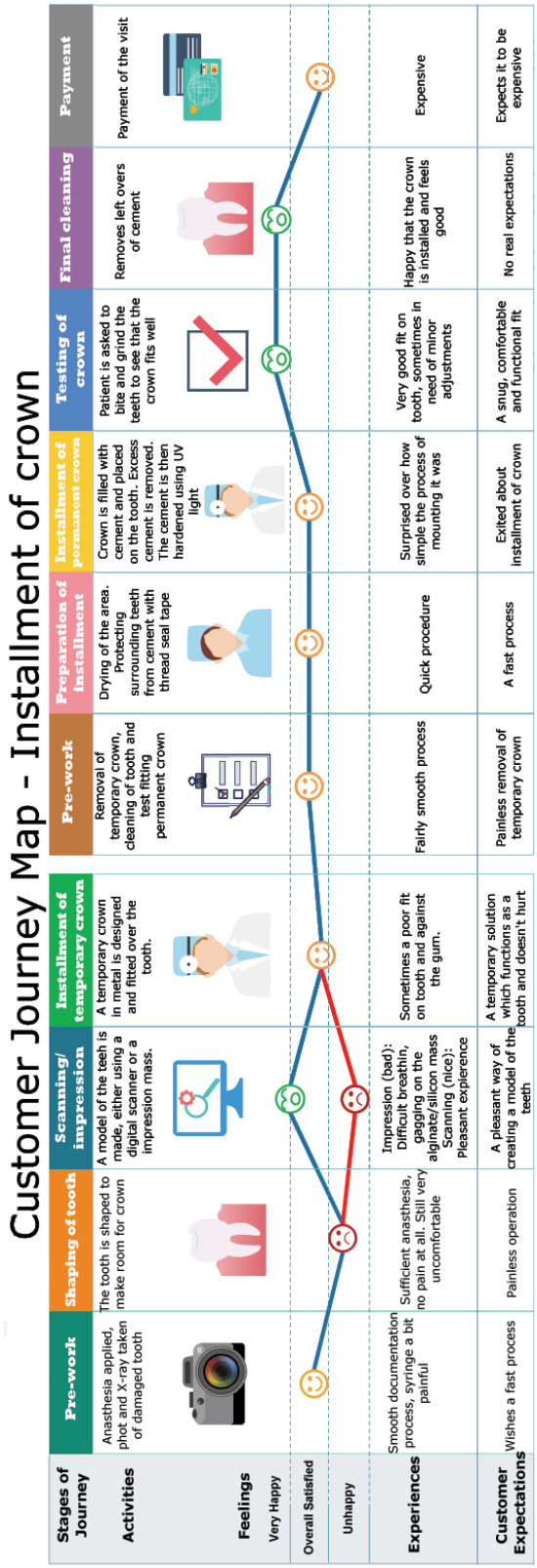


Figure C.1: Illustrative customer journey map of patient undertaking a crown replacement process

D

Choice of area

This material were used to help present different areas for the thesis to pursue during the elimination meeting with the initiating company. The areas are briefly described with including SWOT-analyses. The graphics have been made with Office PowerPoint.

Suggestion: AM Zirconia Crowns

On the commercial market right now there is no crowns in Zirconia made with AM (or other ceramic material). The literature review shows some articles claiming that production of Zirconia crowns with AM is doable.

- Investigation on what is missing for it to become commercial
- Calculations on cost compared to milled crowns
- Possible for studios to have their own printer?
- Type of post processing needed?

Figure D.1: Description of suggestion 1

Figure D.2: SWOT analysis of suggestion 1

Figure D.3: Description of suggestion 2

Figure D.4: SWOT analysis of suggestion 2

Suggestion: Investment in machine park (Hononga as a lab/manufacturer)

Dental laboratories seems very specialised within their field. For Hononga with connections over a diverse spectrum of fields (e.g within medical fields), some similar areas might make use of the same machines. Which could be beneficial for investments.

- Hiring of technicians
- Cross-field specialisation and cooperation
- Specialization on extra difficult cases?
    - Could get extra difficult cases from normal labs as well

Figure D.5: Description of suggestion 3

Figure D.6: SWOT analysis of suggestion 3

Figure D.7: Description of suggestion 4

Figure D.8: SWOT analysis of suggestion 4

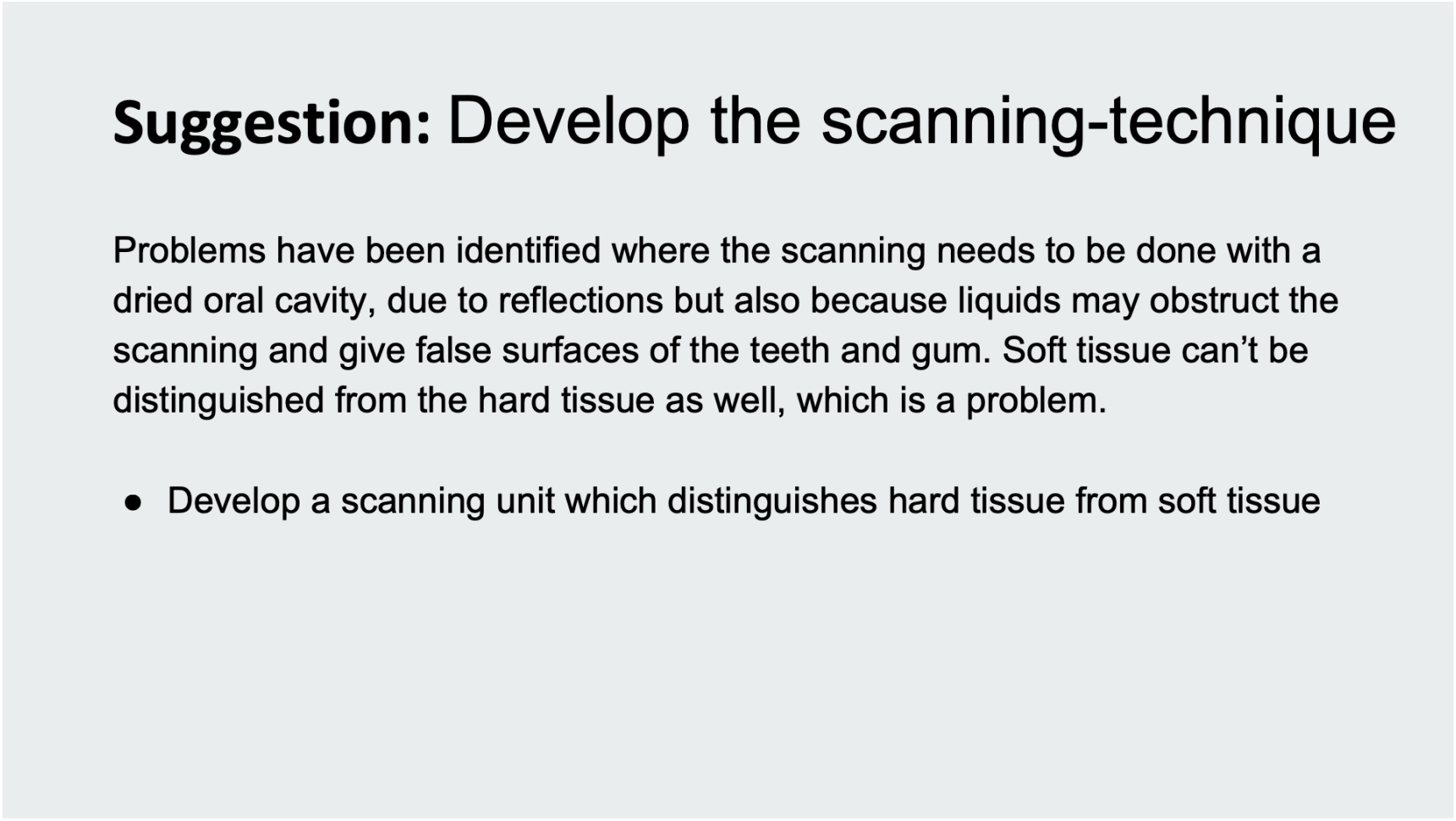


Figure D.9: Description of suggestion 5

Figure D.10: SWOT analysis of suggestion 5

Suggestion: Implants done with AM

Implants made with AM have some benefits shown by article "". Business research if it's worth it?

This suggestion focuses on to what extent it's profitable and doable to 3D print implants instead of today's production method (cutting and shaping of long rods into implants)

Figure D.11: Description of suggestion 6

Figure D.12: SWOT analysis of suggestion 6

Suggestion: AM crowns and digitalisation

Suggestion **AM Zirconia crowns** merged with **Selling digitalisation to more independent studios**

Action plan

1. Comparison of milling vs. 3D-printed crowns
2. Define a Hononga Digital Dentist service
3. Test work-flow for a crown physically

Figure D.13: Description of suggestion 7

Figure D.14: SWOT analysis of suggestion 7

E

Business Model Canvas

Included here is the general Business model canvas (BMC) made with a focus on a Private dental studio. The first BMC is for the Private dental studio, second is for Dental lab, third is for Dental machine manufacturers and the forth and last is Suppliers.

The Business Model Canvas

Designed for: Dental studio (private)

Designed by:

On:

Iteration:

Key Partners

- Dental labs
- Suppliers
- Machine manufacturers

Key Activities

- Routine check-ups
- Procedures

Key Resources

- Studio
- Dental machines
- Expendables
- Dentists + personell

Value Propositions

- Oral aesthetics
- Oral health

Customer Relationships

- Long-lasting (one-time)

Channels

- Phone | (sms) (call)
- Email
- Website (booking)

Customer Segments

- Patients

Cost Structure

- Rent
- Expendables
- Salaries
- Machines
- Dental labs

Revenue Streams

- Patients [on location / future]
- Society (Government)

The Business Model Canvas

Designed for: Dental lab.

Designed by:

On:

Iteration:

Key Partners

- machine manufacturers
- Suppliers
- (scanning companies) Digital O.

Key Activities

- manufacturing
- Designing

Key Resources

- manufacturing machines
- Lab-technicians

Value Propositions

- Dental products (Crowns, sitting implants)

Customer Relationships

- Responsible for quality

Channels

- (Scanning companies) Digital O.
- mail services

Customer Segments

- Dental studios

Cost Structure

- Expendables
- Machines
- Shipping Fees
- Rent
- salaries
- Licences

Revenue Streams

- Payed per product delivered

The Business Model Canvas

Designed for: (Dental) Machine manufacturers

Designed by:

On:

Iteration:

Key Partners

Suppliers

Key Activities

Manufacturing

Support

Key Resources

Expertise

Brand

Value Propositions

(Dental) machine

Support

Customer Relationships

Long-lasting

Channels

Phone

Website

Visit

Customer Segments

Dental lab.

Dental studio

Cost Structure

Manufacturing

Development

Salaries

Support

Revenue Streams

Sales

The Business Model Canvas

Designed for: Suppliers

Designed by:

On:

Iteration:

Key Partners

Sellers of specific materials

Key Activities

Buying

Selling

Key Resources

Expertise knowledge

Logistics

Sellers

Value Propositions

Material to buy in one place

cheaper (buying bulk)

Customer Relationships

Trusting

Channels

Website

Transport

Customer Segments

Dental lab.

Dental studio

Cost Structure

Buying material

Salaries

Rent (storage)

Transport

Revenue Streams

Sales

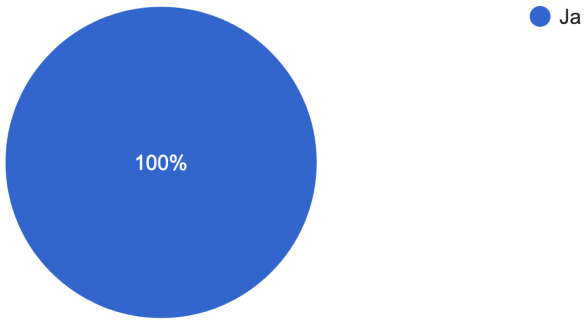
F

Market Survey

The conducted market survey was an online questionnaire which was sent out to Swedish dental studios by email. The survey was done in Swedish. Some selected extra relevant Figures are translated to English and put in the end of this Appendix. The online questionaire were created in Google Forms, were also the pie-charts and overviews were made.

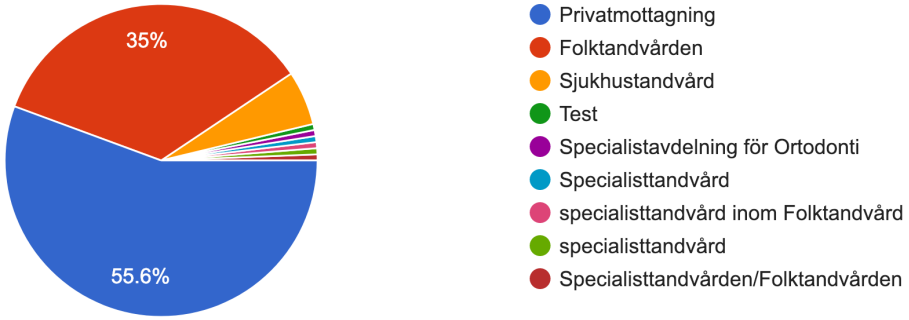
Jag är medveten att alla svar jag ger är helt anonyma, att resultatet av den insamlade datan kan komma att publice...de att datan används för detta syfte.

160 responses



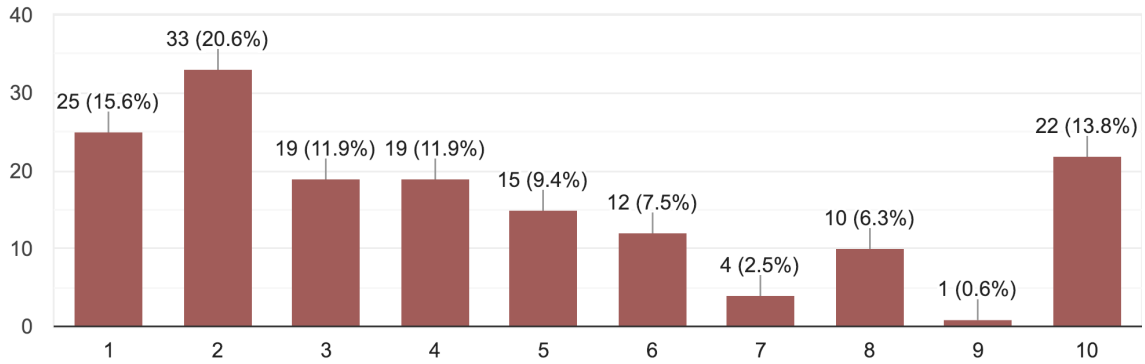
Vad för slags mottagning har ni?

160 responses



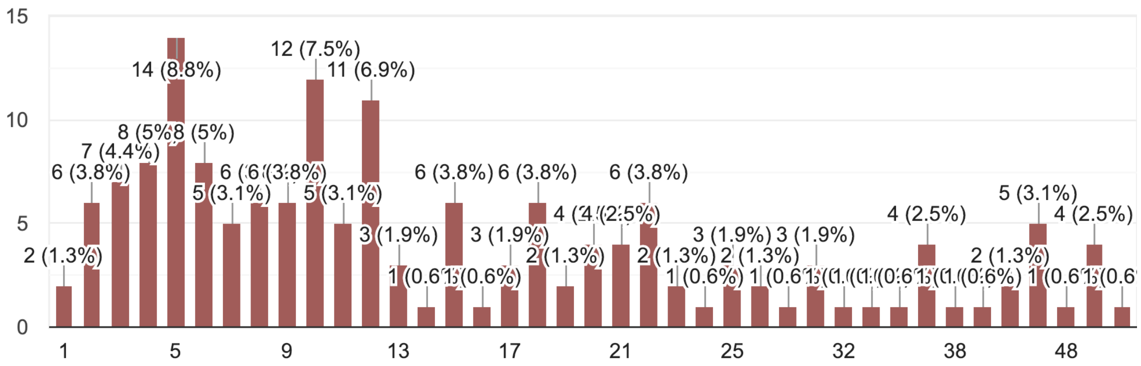
Hur många legitimerade tandläkare är det på er klinik?

160 responses



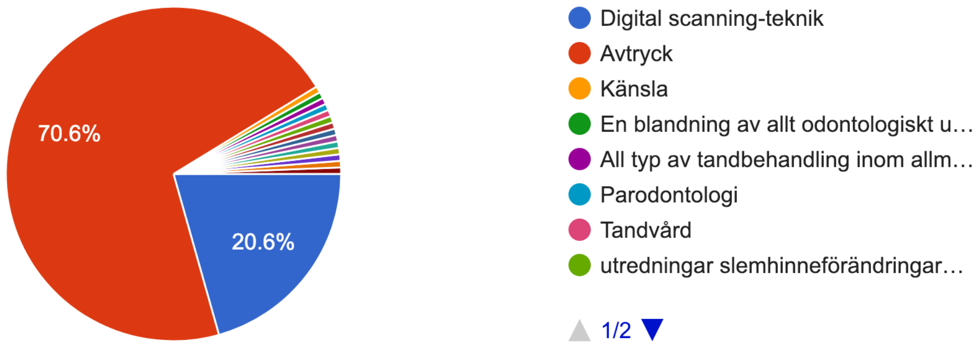
Hur många anställda är ni på er klinik totalt?

160 responses



På vår klinik arbetar vi främst med:

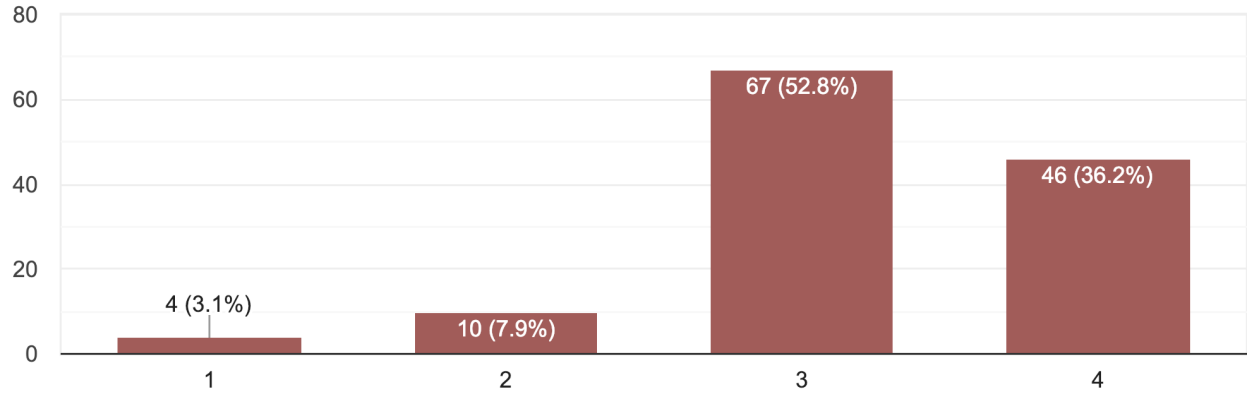
160 responses



Impression Mass respondents

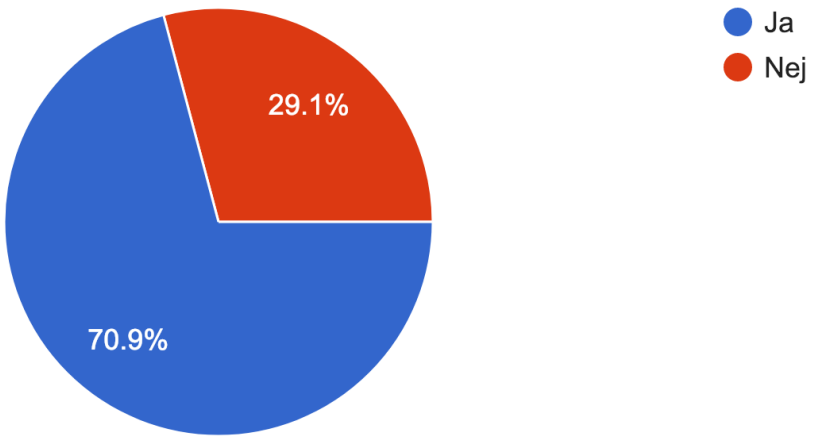
Hur nöjd är ni med er process?

127 responses



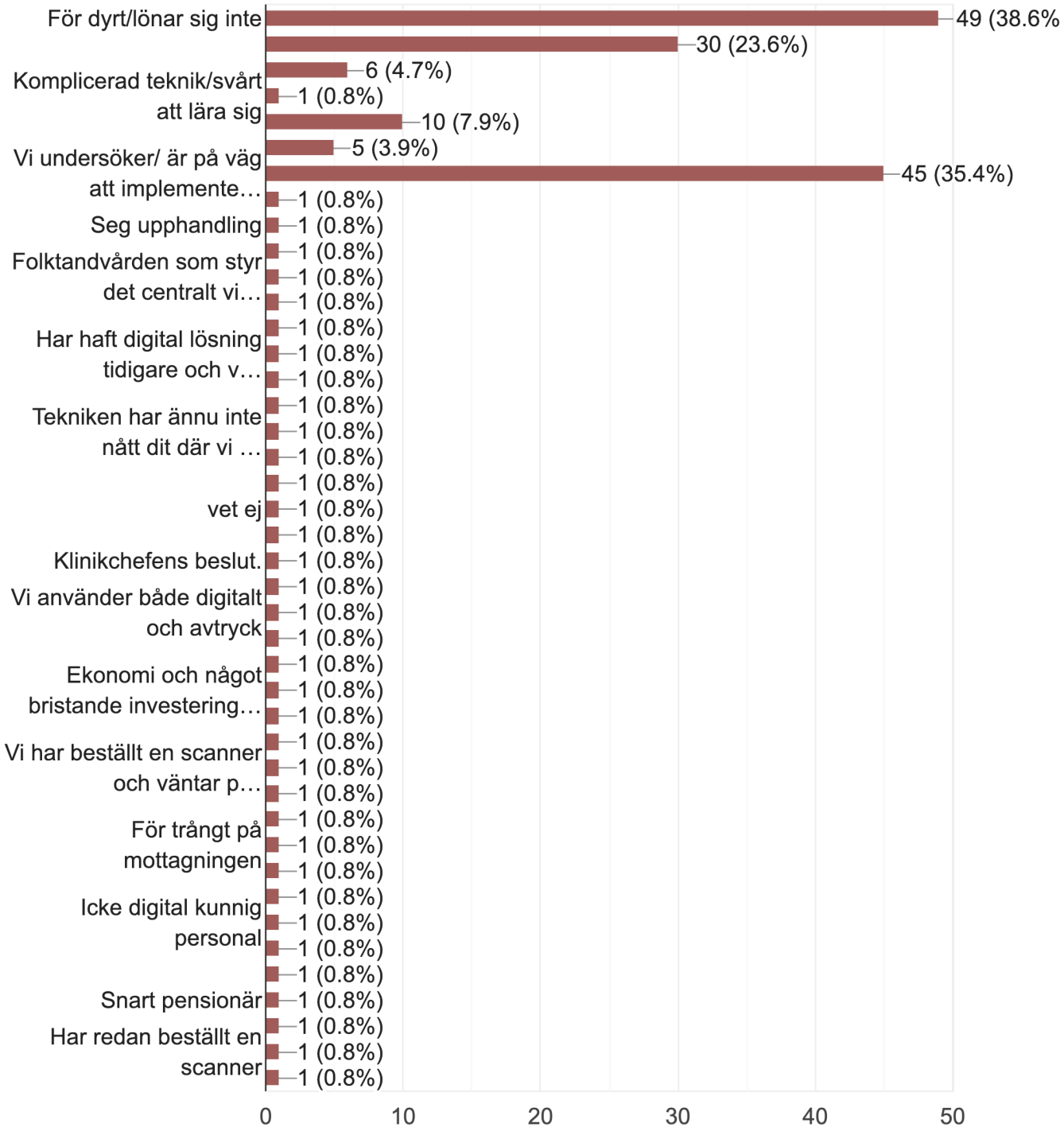
Skulle ni vilja gå över till digital scanning-teknik?

127 responses



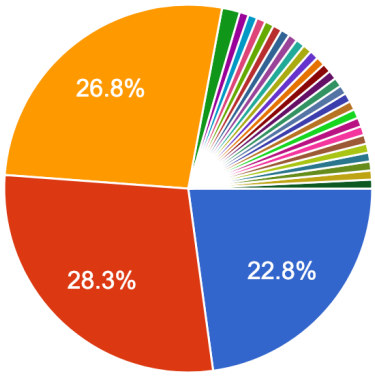
Varför har ni inte övergått till en digital lösning? (kan välja flera)

127 responses



Skulle ni vilja testa på digitala lösningar i er klinik?

127 responses

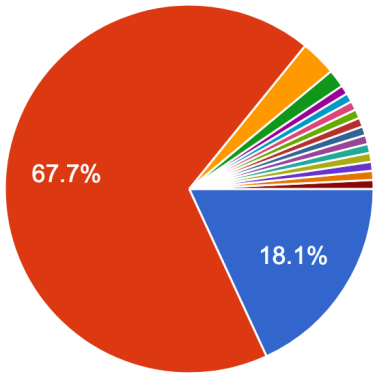


- Ja
- Ja, om det är gratis
- Nej
- Har testat
- Har redan gjort det och nu är det up…
- VGR har redan upphandlat denna t…
- om det passar..
- Vi har pilotkliniker.

1/4

Skulle ni vilja ha en tjänst där ett företag kom till er om ni nån gång ibland skulle behöva ta digitalt avtryck (eller dylikt) och då hjälpte till med detta?

127 responses

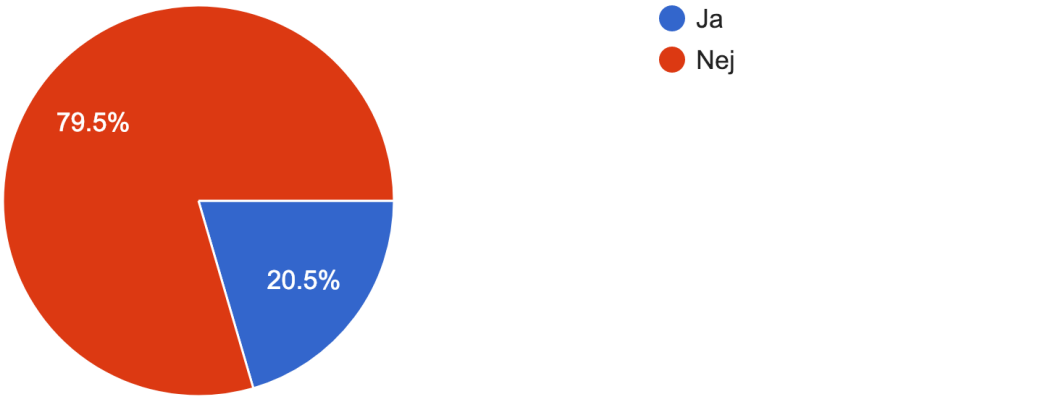


- Ja
- Nej
- vet ej
- Vet ej
- finns kompetens inom företaget
- sällan vi gör det
- Osäker
- Kanske längre fram

1/2

Skulle ni vilja tillverka kronor/bryggor etc på er klinik? (In-house)

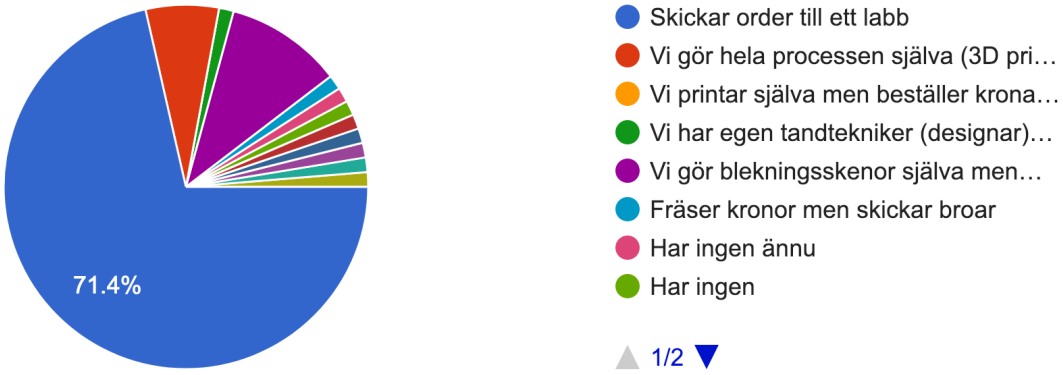
127 responses



Digital Scanning

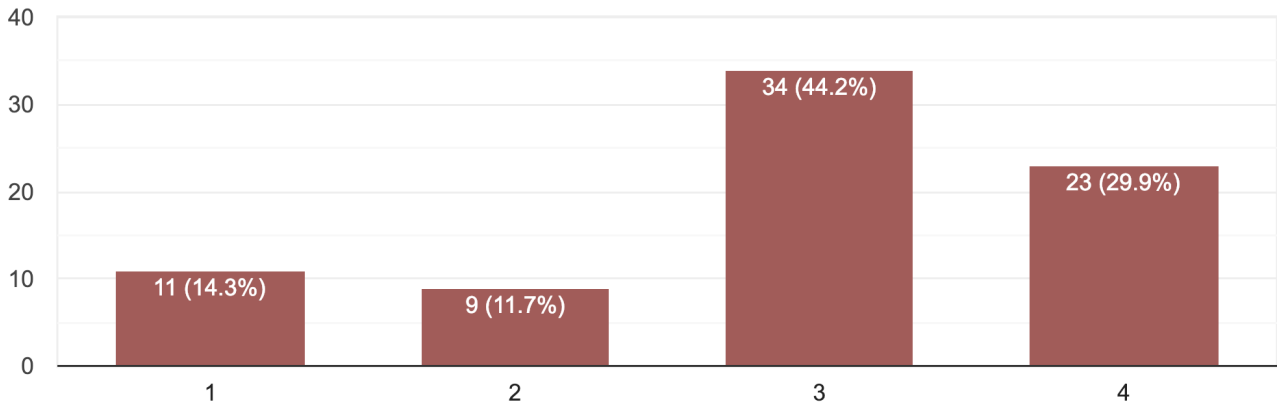
Har ni tillverkning in-house eller skickas en order till ett externt labb?

77 responses



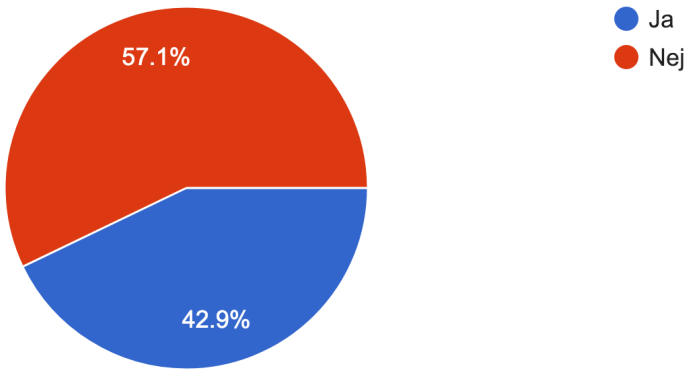
Hur nöjd är ni med er process?

77 responses



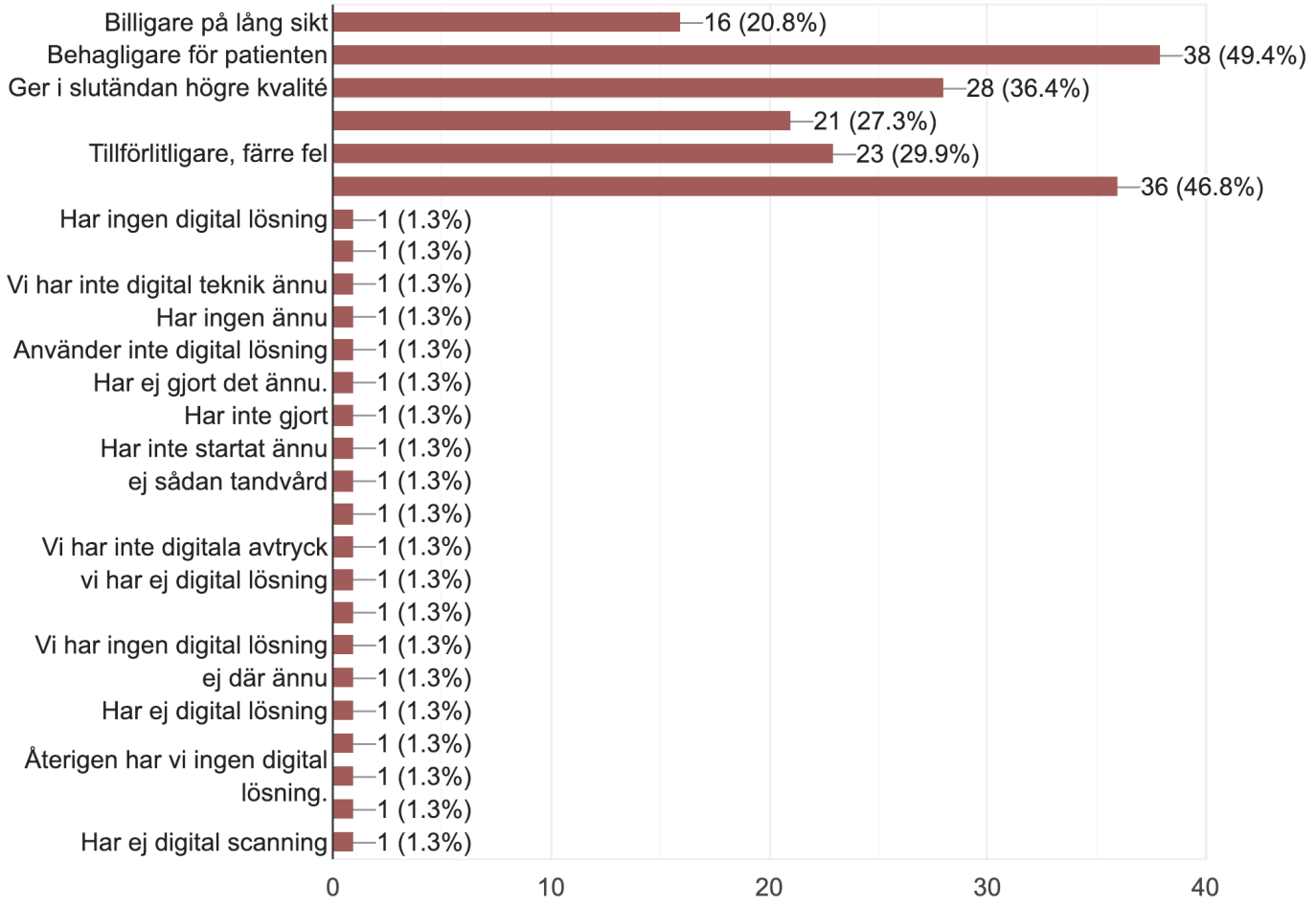
Skulle ni vilja ha tillverkning av kronor/bryggor etc. in-house på er klinik?

77 responses



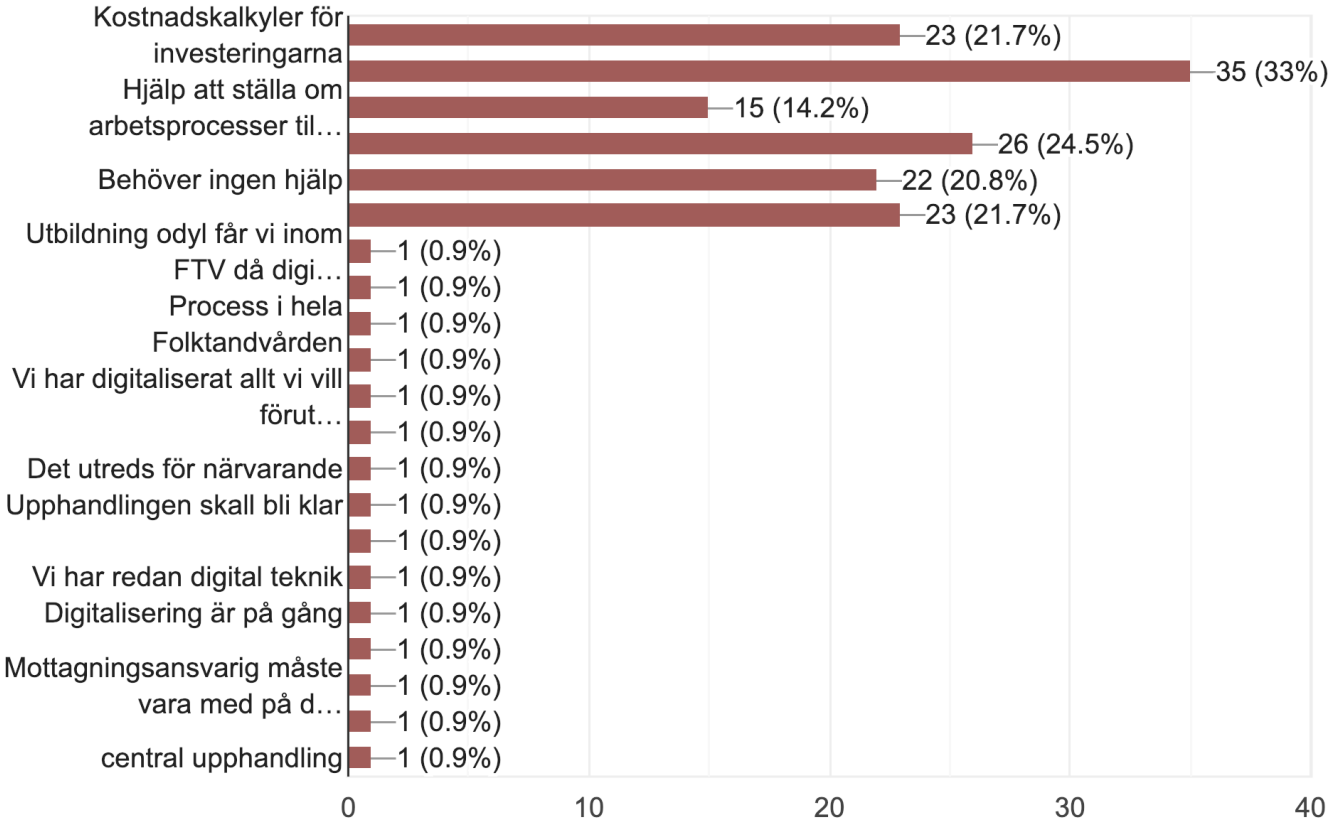
Vad var anledningen till att ni gick till en digital lösning? (kan välja flera)

77 responses



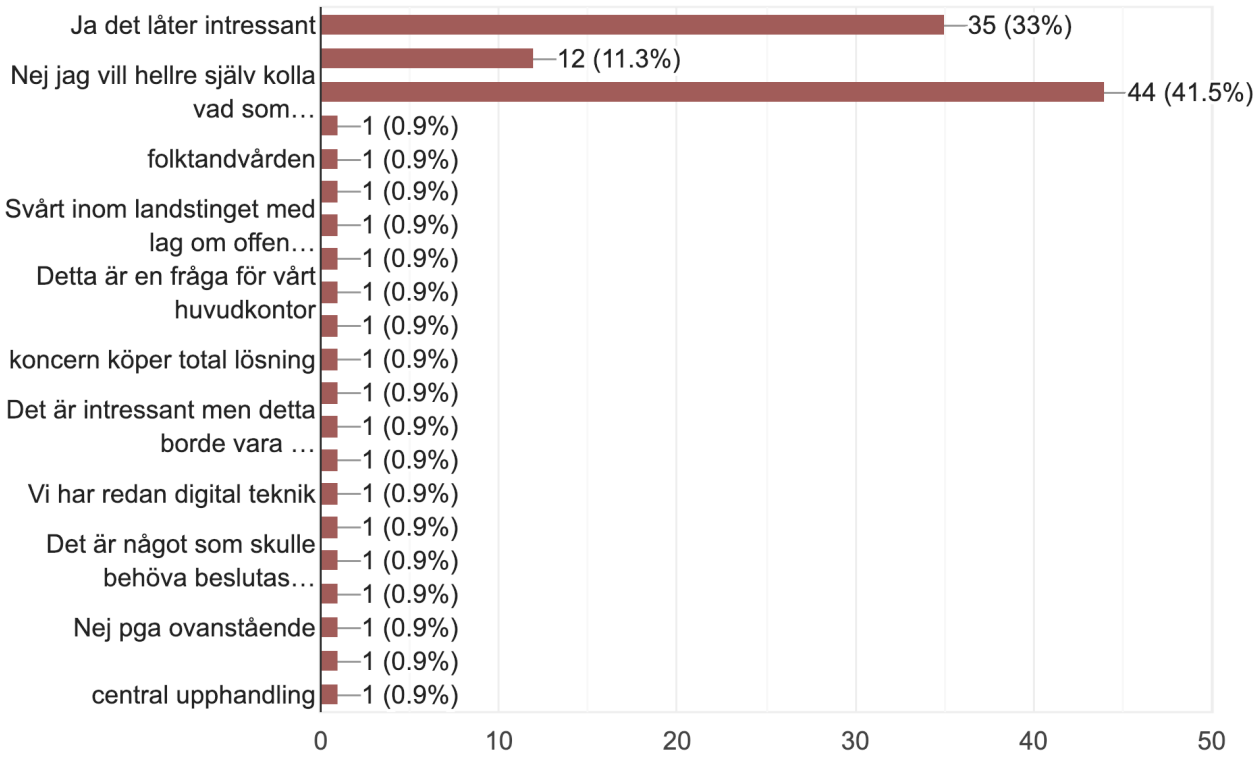
Vad för typ av hjälp behöver ni för att gå över till digital teknik?

106 responses



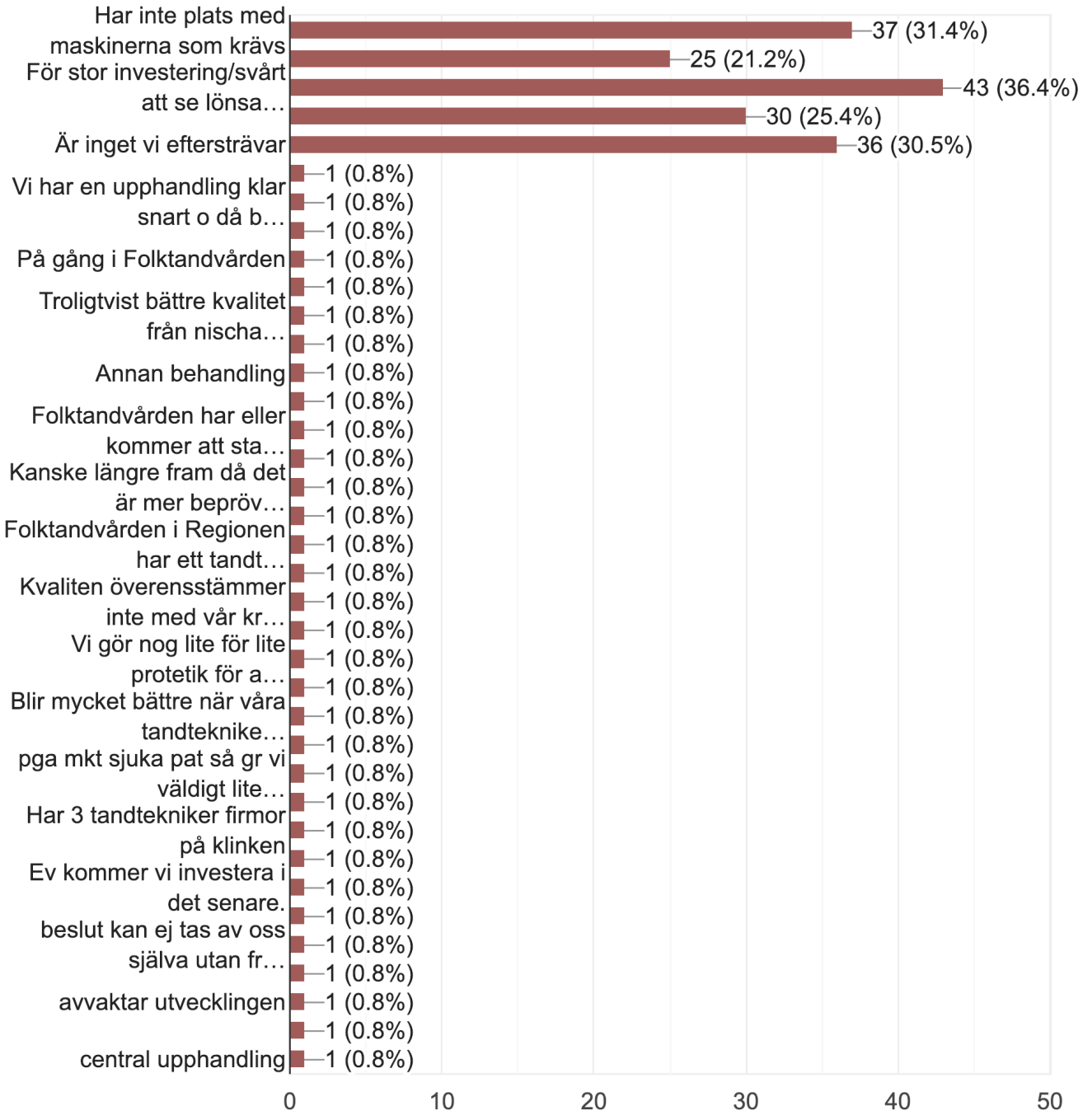
Hade ni varit intresserade av möjligheten att köpa en tjänst som levererar en hel digital lösning, skräddarsydd f...av produkterna och mjukvaran hos er?

106 responses



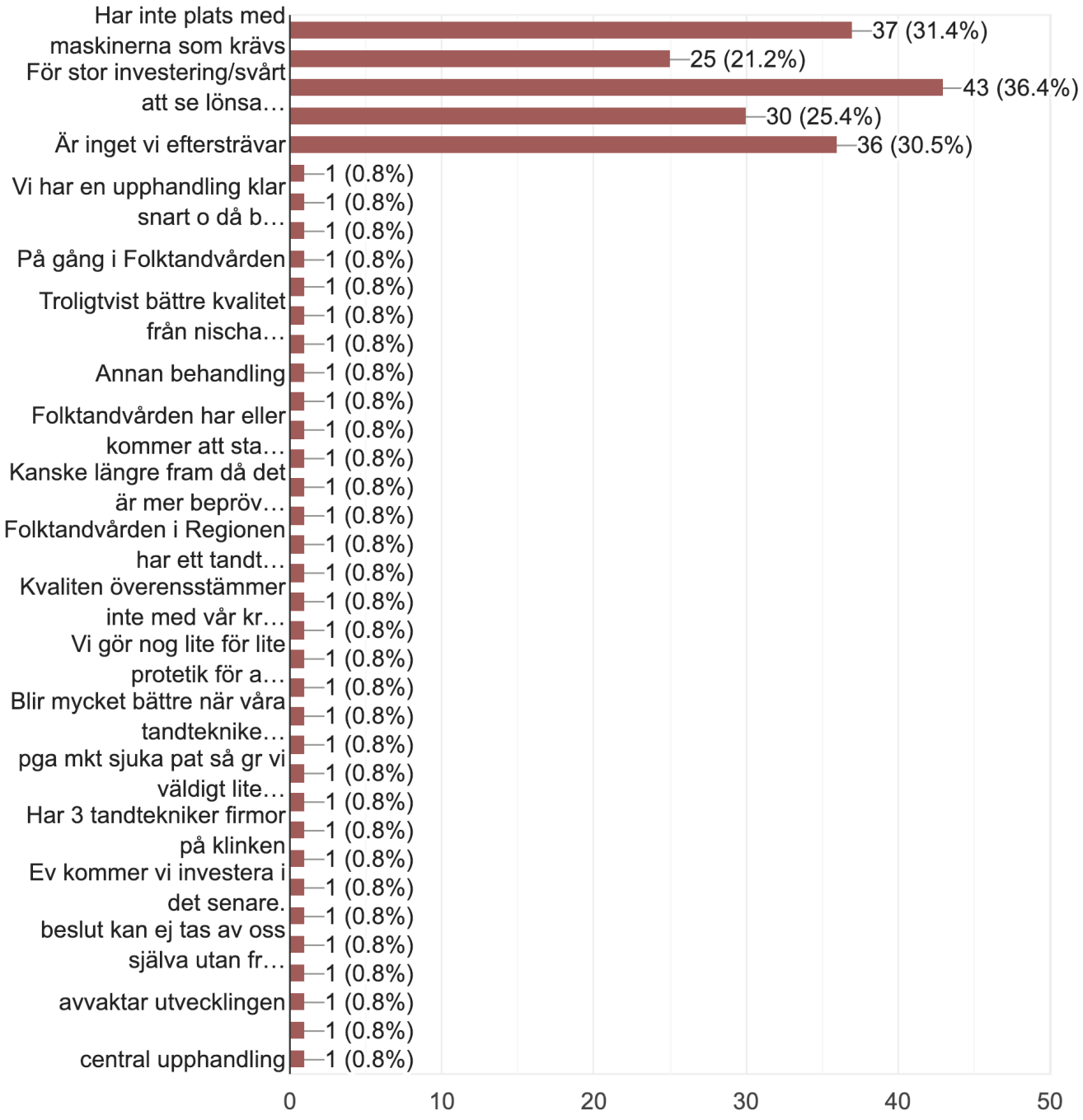
Vad hindrar er från att ha in-house produktion? (kan välja flera)

118 responses



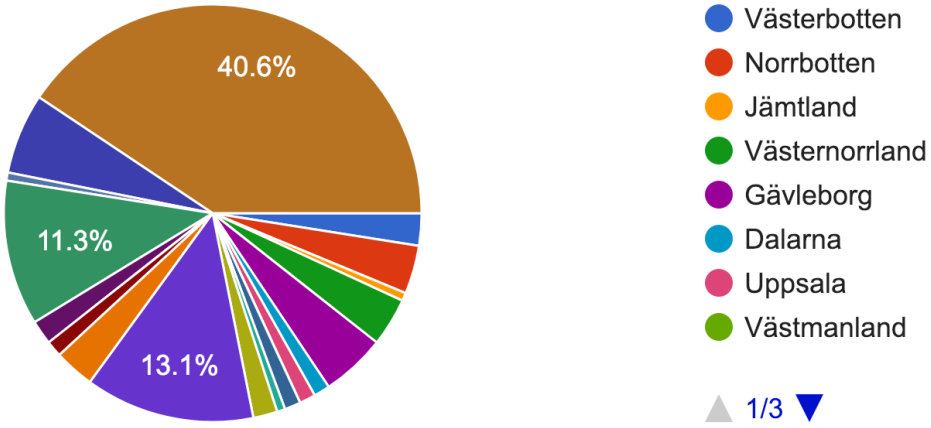
Vad hindrar er från att ha in-house produktion? (kan välja flera)

118 responses



I vilket län befinner sig er mottagning?

160 responses



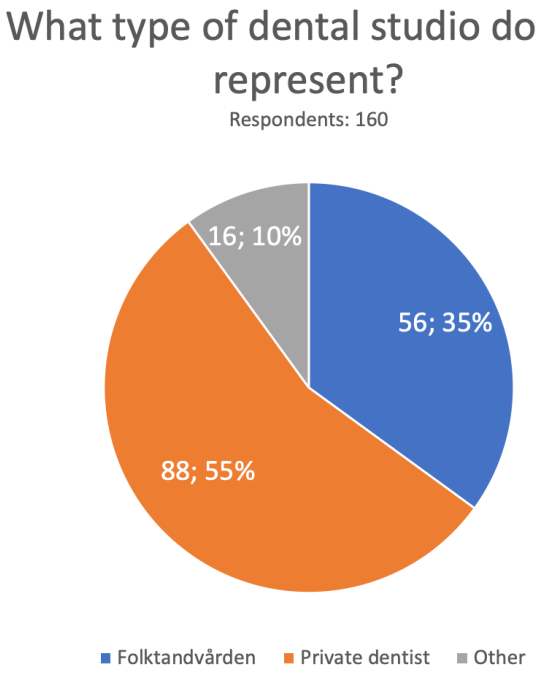


Figure F.1: Distribution of the type of dental studio the respondents represent.

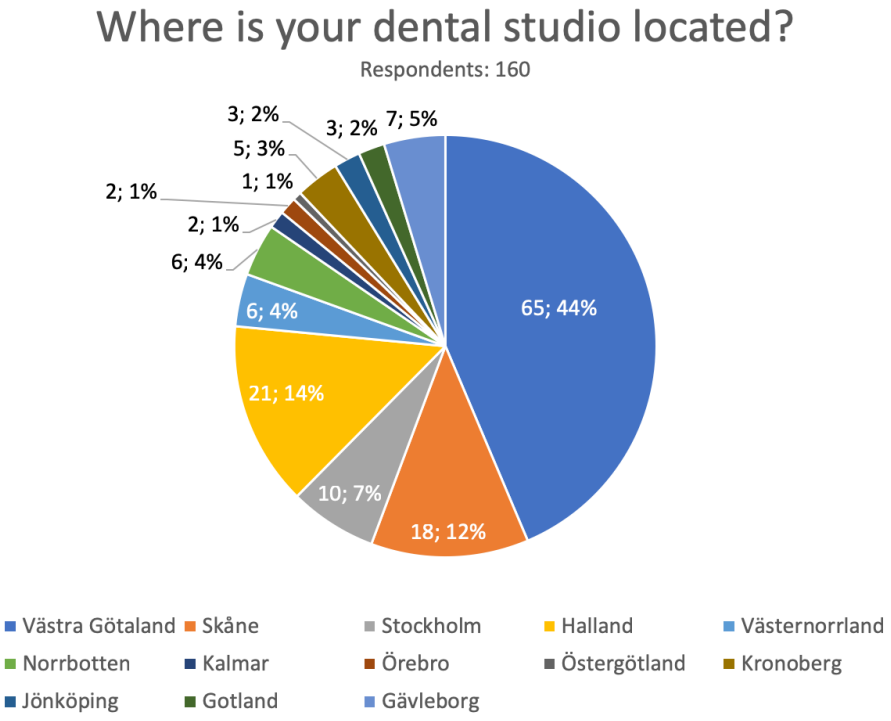


Figure F.2: Figure illustrating distribution of geographical location in Sweden of respondents.

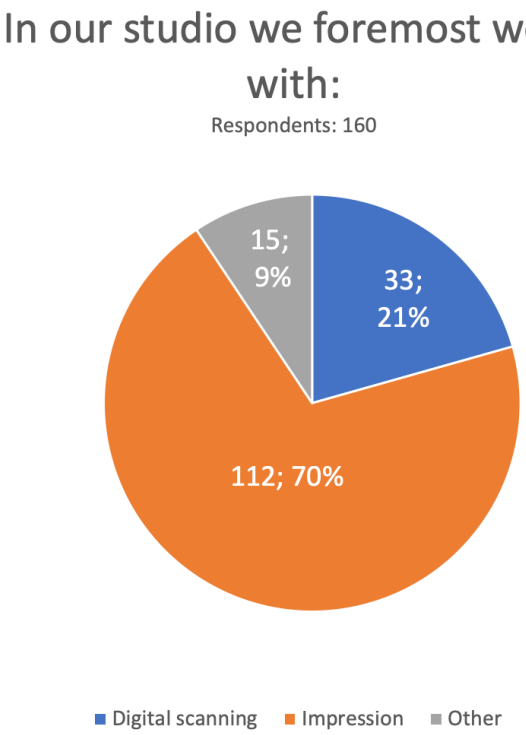


Figure F.3: Figure showing the distribution of what type of technology the dental studio currently uses.

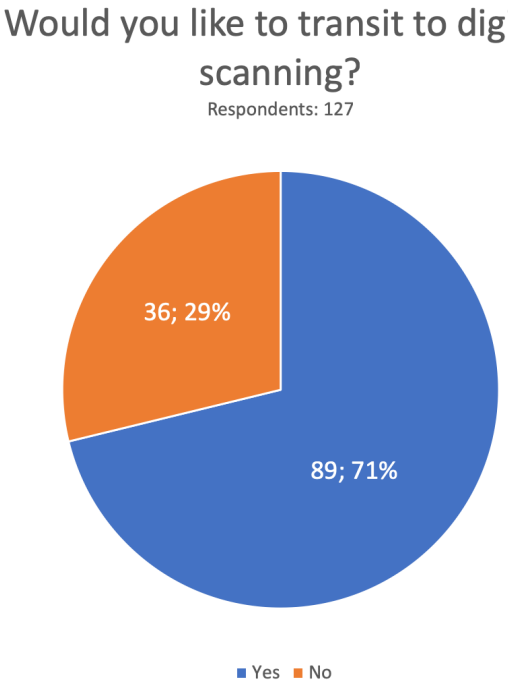


Figure F.4: Answers illustrating the willingness to change from analogue impression to digital scanning.