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Creating a Communication Network in Additive Manufacturing

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WPI

Sponsored by
Dr. Ivo Dobrev &

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Abstract

Additive manufacturing (AM) is a relatively new processing technique that has grown exponentially over the past decade. As its potential in the medical community becomes more realized, there is an increasing effort between researchers and institutions to communicate efforts and partnerships. Our sponsor, Dr. Ivo Dobrev from the Universitätsspital Zürich's otorhinolaryngology clinic, wishes to expand the department's research to encompass AM, and therefore our team set out to create a social network of institutions providing AM resources for the benefit of future projects at the hospital. We interviewed and researched AM companies to provide a meaningful database of resources, and subsequently created an interactive application as an easy and concise reference for the future.

Executive Summary

Problem

While the potential for additive manufacturing (AM) technology is seemingly boundless, the technology has seen slow adoption by the medical community. This is partly a consequence of the fact that research in AM is concentrated in a relatively small number of universities, companies, and hospitals, stifling communication outside of academia. In addition, the content matter of this research has incredible breadth, encompassing many types of printing technologies, from inkjet to heat extrusion to laser transfer, and still more types of printable materials (Steenhuis, 2016). Even major hospitals struggle to sift through the large volumes of recent research in order to begin implementing these solutions. As a result, there is a pressing need to consolidate existing knowledge about AM techniques in medicine in order to make them more accessible to other researchers and medical professionals.

Goal

To create a network of institutions which provide knowledge and services that would allow the University Hospital Zurich's department of Otorhinolaryngology, Head and Neck Surgery (ORL) to make use of AM in their research.

Figure 1 – University Hospital Zurich (www.usz.ch)

Plan

1. Assess the ORL's prior knowledge of AM
2. Identify and interview institutions which can provide useful knowledge and services to the ORL
3. Consolidate the gathered information into a compact and easily-accessible format

The first objective was to assess the ORL's prior knowledge of AM. In order to better understand the needs of the ORL, we conducted interviews with as many ORL personnel as possible to ascertain their current knowledge on AM technology, as well as their goals and needs.

The second objective was to identify and interview institutions which could provide useful knowledge and services to the ORL. This step represented the majority of the work in this project. To begin, we had to create a preliminary list of organizations to interview, assembled from a variety of sources. One major way in which we gathered more contacts was by attending two events for medical professionals- The ORL's own 100-Year Symposium, and the 2017 MedTech Expo in Lucerne. The interviews were conducted similarly to the internal interviews, and snowball sampling was utilized in the interviews to build a larger network of potential partners for our sponsor.

Our third objective was to consolidate and present gathered information. In order to most effectively present the data to our sponsor we created a standardized data form that summarizes the capabilities of each institution, as well as additional notes on an *ad hoc* basis. Furthermore, since the resulting mass of data was still somewhat cumbersome, a web application was created to help sort and visualize the data better. The web app featured an interactive network graphic of all the institutions interviewed, with edges in the network representing when one organization directly referenced another one in an interview.

Findings

As our project progressed, our team was able to generate several key findings, through both our interviews and research. First, we discovered that **many use cases that interest the ORL do not currently appear to be commercially available.** Every ORL member whom we interviewed was able to suggest a list of potential AM applications to their work, but almost none of them are actively pursuing projects which could make use of these applications, with the exception of the clinic making use of 3D-printed models from the company Phacon for training surgeons.

Figure 2 – Phacon Training Model (www.phacon.de)

This stems for the lack of maturity of medical AM in general; no companies have yet endeavored to develop this admittedly niche category of products. However, while there may be no obvious immediate uses for AM in the ORL clinic, the personnel whom we interviewed were still generally enthusiastic about it, which we found to be important.

While attending the Swiss MedTech Expo, we discovered that **there are groups that are trying to facilitate communication between researchers and the companies who supply AM technology.**

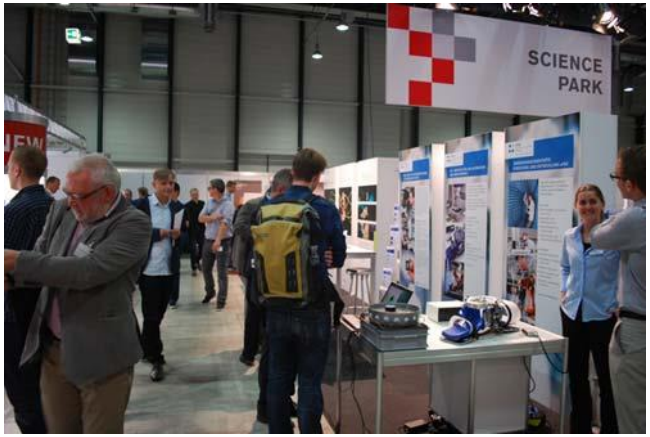

Figure 3 – Swiss MedTech Expo

One business in particular is directly addressing poor networking between AM companies and potential customers. The AM Network (https://www.amnetwork.ch/en/) was launched at the beginning of this year, and our team asked the president of the business, Markus Baertschi, questions about his desire and goals for this website. Mr. Baertschi informed our team that the AM network attempts to address the lack of communication in the field of AM, and wishes to create a formal collaboration between businesses and contracts for people such as USZ to get help towards the right resources. Places involved in the usage or research of AM are aware of the fact that there has been poor conversation among groups and there is room for improvement, which will hopefully lead to more collaboration and business agreements between researchers and product providers.

Our interview with medical professionals also led us to the discovery that **while the expansion of additive manufacturing companies into the medical field is new, it is a rapidly expanding space**. At the MedTech exposition we were able to speak to a

multitude of people working in additive manufacturing. While these companies are very new in the medical field, each interviewee expressed an interest in expanding their horizons in the field. This showed us that while the technology that the ORL team is seeking is not available at the moment, there is immense potential in the research and applications utilized by companies in AM.

The results of our interview process indicated that there is a great deal of knowledge to be gained by consulting with a relatively small number of medical experts who are familiar with AM. **By tapping into the knowledge of experts, a detailed view of a variety of different AM technologies and services becomes available.** These medical experts were able to help us construct a large network of a diverse variety of companies, research groups, and applications by simply asking them whether they knew of any other institutions which were doing relevant work. This further supported the notion that focusing on communication within the research community would ultimately be much more rewarding than reaching out to most companies in order to understand the currently-available resources and applications for AM in medicine.

Recommendations

Using our findings, our team was able to suggest three key recommendations for our sponsor and his team at the University Hospital Zurich.

There are a large number of possible applications of AM technology in medicine, many of which may require in-depth technical knowledge to properly implement. While this project aims to present a starting point for accessing these applications, it is likely that more information will need to be gathered before they can be fully utilized. To this end, we recommend that when the USZ requires further knowledge about a certain application or technique of AM, **they should tap into the knowledge of medical researchers**. Each research institution that we spoke to yielded a tremendous amount of information, and thus we believe that research personnel at the ORL would benefit greatly from contacting these researchers directly. More specific contacts for these locations are available in the data forms which we are providing to the ORL.

One of the central problems which this project aimed to address is the lack of communication between various stakeholders in medical AM technology. Out of all the institutions which we interviewed, the AM Network stood out as the one organization which intended to directly address this same obstacle. **Thus, we recommend that the ORL contacts AM network**. Out of all the institutions investigated during this project, no other group brings together such a diverse body of expert knowledge, and no other group has such a strong focus on promoting collaboration.

Finally, it is important that the hearing research **team stays up to date with developments in AM**. Most AM companies have only recently begun entering the medical field. For this reason, the technology is very new, and in order to be used in the applications that the USZ hearing research team are seeking, will require some further technological development. Thus, it is important that the research team continues monitoring developments in AM.

Authorship Table

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Chapter 1 – Introduction

In the USA alone, 22 people die every day while waiting for an organ transplant ("Organ Procurement and Transplantation Network," n.d.). A technology called additive manufacturing (AM) may one day eliminate this problem altogether, by allowing on-demand biofabrication of living organs. AM, also known as 3D printing, is a relatively new technology which promises to revolutionize many industries, including the field of medicine. This is because AM offers unique advantages to the medical world over many incumbent manufacturing techniques. There are already a myriad of promising results in research experiments ranging from creating middle ear ossicular replacement prostheses, which have proven to be difficult to manufacture out of conventional materials, to printing of living material that may one day be used to create entire living organs (Ovsianikov et al, 2007). AM is particularly well-suited to tasks like this, as it makes it possible to create extremely intricate, personalized structures out of a growing variety of materials with greatly reduced turnaround time compared to traditional manufacturing. Indeed, in the not-so-distant future, it may be possible that these monstrous problems of today, hearing loss and transplant waiting lists, will only exist in history books, thanks largely to AM.

While the potential for AM is seemingly boundless, the technology has seen slow adoption by the medical community. This is partly a consequence of the fact that research in medical applications of AM is concentrated in a relatively small number of universities, companies, and hospitals, stifling communication outside of academia. In addition, the content matter of this research has incredible breadth, encompassing many types of printing technologies, from inkjet to heat extrusion to laser transfer, and still more types of printable materials (Steenhuis, 2016). Even major hospitals can struggle to sift through the large volumes of recent research in order to begin implementing these solutions. As a result, there is a pressing need to consolidate existing knowledge about AM techniques in medicine in order to make them more accessible to other researchers and medical professionals.

Due to these challenges, the researchers for the Otorhinolaryngology, Head, and Neck Surgery Clinic (ORL) at the UniversitätSpital Zürich (USZ; English: University Hospital Zurich) have become interested in developing an overview of currently-available AM technologies. Having access to such knowledge would allow them to begin to make use of AM in their research of otology, and reap some of its many benefits. However, as a group of highly specialized experts, they face a substantial knowledge gap which impedes their access to currently available AM resources. The goal of this project was to identify a network of institutions which can provide the knowledge and services that will allow the ORL's researchers to implement AM in their work. In order to accomplish this goal, we conducted on-site interviews to assess the ORL's prior knowledge of AM applications, employed snowball sampling and interviewing to identify a network of institutions which could provide relevant AM resources, and finally, consolidated the data into standard per-institution data forms. To further aid readability, this data was then presented via a web app, which also provides a network visualization that serves to illustrate the inter-institutional connections we observed from our interview process.

These methods resulted in a rich set of data which allowed us to draw sophisticated conclusions about the current ecosystem around AM technologies. Based on these findings, we were able to create recommendations that we believe will equip the ORL to effectively utilize AM technology to advance their work in otology.

Chapter 2 - Literature Review

Optimal success in creating a connection network for our sponsor presents the need for evaluating the history of Additive Manufacturing (AM). A brief background of the University Hospital Zurich (USZ), the organization which has requested this project, is provided, followed by a minimally technical overview of several currently-existing AM techniques which may be of interest to the researchers at USZ. An identification of what has succeeded and failed in the past will provide us valuable context to how we frame our own investigation. Furthermore, identifying which of our stakeholders might be inhibiting the adoption of AM will allow us to accurately select the communities we will investigate. Finally, we present two case studies in which information was consolidated with the purpose of implementing new technologies in practice, similarly to the goal of this project.

2.1 The University Hospital Zurich

The University Hospital Zurich (USZ) is host to one of the largest communities of doctors and medical researchers in Switzerland. According to the USZ statistics page over 1,250 doctors, 2,500 trained nurses, and 2,000 researchers work at their facilities (USZ, 2017) These medical professionals are providing the highest quality care in the region as well as making significant advances in medical technology.

Figure 1. University Hospital Zurich campus (usz.ch , 2017)

The information which will be gathered by this project will be most directly related to work being done by the researchers and doctors working in the hospital's ear, nose, and throat clinic, the "Klinik für Ohren-, Nasen-, Hals- und Gesichtschirurgie" (ORL). This department is the center of otological research and procedures in the hospital. Doctors in this department perform a variety of surgical procedures on the ear, especially those related to hearing restoration. Key research topics include the mechanics and causes of hearing loss, as well as new potential treatments for these conditions.

More specifically, our team will be working directly with the "Otology + Biomechanics of Hearing" team at the ORL. The team is personally led by the head of the ORL, Dr. Alexander Huber, and consists of both doctors and researchers. Members stand to benefit directly from prototyped models due to their huge potential in research, education, and practice. Furthermore, the team is primarily interested in building potential partnerships in order to have comprehensive access to the knowledge and resources necessary for utilizing functional models.

Since rapid prototyping has already been successfully used in both creation of surgical models and in creation of middle ear prostheses (Neff, 2017), there is no doubt that these researchers could benefit from such technology. However, the question still stands as to whether there are locally available resources which would enable a cost-effective, speedy, and effective path to adoption by USZ.

2.2 Existing Applications of Modelling Technology in Otology

In order to properly understand the available resources and potential paths to adoption of AM for USZ, it is critical to be aware of modelling techniques which are already being used in medicine, particularly those relevant to otology. Several studies have been conducted in which researchers have recreated parts of the ear for various applications. One team, made up of scientists based in Germany and the US, created ossicular prostheses out of bio-friendly materials, which they consider to have potential for use in humans (Ovsianikov et al, 2007). A second team was able to create a mechanically accurate model of a middle ear which they believe may be used for prosthesis research (Kuru, Maier, Müller, Lenarz, & Lueth, 2016). An additional study found it possible to create sophisticated replicas of the tympanic membranes, another extremely delicate and complex part middle ear organ (Kozin et al., 2016).

These models, created by 3D printing, are not only very accurate, but may also be less expensive than those created with traditional manufacturing processes, as they require less expensive equipment and materials. This makes them promising for applications such as creating inexpensive, realistic surgical models, as well as performing mechanical studies without needing cadaver parts, which are more expensive and volatile (Narayan, 2007; Mowry, Jammal, Myer, Solares, & Weinberger, 2015). These studies only scratch the surface of what may be possible with various 3D printing technologies, as other studies have successfully used similar approaches to create functioning models of a variety of organs, including livers, craniofacial bones, and musculoskeletal tissues (Hung et al., 2016; Warren, Huebner, Spang, Shirwaiker, & Fisher, 2016; Lee et al., 2017).

A notable gap in the current scientific literature on physical otological models arises from the fact that virtually no *in vivo* human tests appear to have been conducted on 3D-printed internal prostheses, nor do any experts appear to have worked together to establish a set of best practices for 3D printing. These both seem likely to stem from the fact that it is still a very young technology. Regardless, many of the discussed applications of 3D printing in medical research do not require human testing, as is the case with creation of surgical models and prosthesis testing, for instance. These applications could potentially be implemented and their benefits reaped in the very near future, so it will be very helpful to the project if we are able to facilitate communication between the researchers familiar with them.

2.3 Challenges to the Adoption of Medical Technology

It is imperative for any project that deals with the potential adoption of a new technology to discuss what the associated challenges are. Medical technology is a rapidly expanding and complex field. Hospitals are constantly dealing with the potential to adopt new technology, but they struggle to make purchasing decisions, due to a variety of reasons. The lack of relevant information is one of the biggest challenges in adopting new technology. Historically, the purchasing decisions that hospitals have made in the past were based on information provided by vendors (M.J. Coye et al, 1999). A 1999 survey of hospitals by the Lewin Group found that less than half of all hospitals used external sources of information other than vendors; and of those using external sources, fewer than one-fifth used research institutes or firms specializing in technology assessment (M.J. Coye et al, 1999). While technology-forecasting firms are slowly entering the market, hospitals are still largely making technology decisions independently of each other, creating a disconnect in the area of decision making (L.H. Friedman and J.B. Goes, 2000).

Furthermore, it is imperative that hospitals purchase technology that there is a proven need for. This often requires lengthy conversations with physicians, researchers, and patients. Patient demand is a direct driver of physician demand, and thus plays a huge role in technology adoption as well (Kravitz et. al, 2002). However, technology purchases are largely dominated by the preferences of doctors, specifically those who play larger roles in the hospitals (IOM, 2001). Thus, it becomes a challenge for hospitals to acknowledge every stakeholder equally in making decisions related to the adoption of technology.

However, there are signs that the status quo is changing. A 2005 survey of twenty health care systems worldwide discovered an overwhelming belief that hospitals "should become more adept at technology innovation and adoption and that technology should play a larger role in their organization's strategy." (HealthTech, 2005). Through the gathering of relevant, neutral information, and a comprehensive analysis of stakeholders, hospitals can make well informed decisions as to whether a technology should be adopted or not.

2.4 Analysis of Relevant Case Studies

Because of the unique challenges of creating a partnership network in the highly technical discipline of health research, it is useful to analyze real world approaches to establishing and maintaining such partnerships. To that end, this section presents two case studies in which actual health partnership networks were established using methodical approaches.

In 2016, a study was conducted by Larkan et. al to identify potential partners for the Centre for Global Health (CGH) at Trinity College Dublin. The purpose of the study was to identify the aspects of a productive partnership in order to facilitate future collaboration with others, which stands in contrast to this project, where we are more focused on finding partners in a much more specific research field. Nevertheless, this study is quite informative because it included outreach to a variety of members of the health community (Larkan et. al, 2016).

The study defines health partnerships as "contextually relevant peer-to-peer collaborations which offer a platform for sharing knowledge and growing expertise globally, working towards a common goal, across disciplines and perspectives," which in our opinion is essentially equivalent to "an arrangement in which multiple institutions collaborate toward a

common goal." This is exactly the sort of relationship that our project is intended to help create for USZ. Subsequently, a three phase approach to identifying potential partners is set forth. The first phase was a broad outreach to a variety of institutions via a very open-ended questionnaire and a subsequent analysis of their responses, the second phase was a consultation with a group of officials at the CGH, and the final phase was the development of a framework to establish successful partnerships in the future (Larkan et. al, 2016).

This methodology forms a very useful basis for our own project, as the pattern of outreach followed by consulting with the home institution provides a good way to ensure that everyone's needs are taken into consideration in producing the final model. However, there are several key areas where our goals differ from the goals in this study. Primarily, the group in the study was only concerned with identifying aspects of a good partnership (to the end of establishing protocol for interacting with other institutions), whereas our study is focused on identifying good partners. The aspects identified by the study, such as communication, focus, and equity can help inform our evaluations in this goal, however, our project also requires a great deal of extra information about each partner, such as their technical capabilities. This suggests that while the CGH study may have functioned by using questionnaires as their primary source of data, our project may require a more in-depth approach such as interviewing.

The second study, "Enhancing Business Intelligence Quality with Visualization: An Experiment on Stakeholder Network Analysis," was chosen due to its focus on creating more useful and appealing ways of representing qualitative data between various businesses. As described early in the article, their approach was to combine "information visualization and Web mining techniques with human knowledge to enable business analysts to analyze and visualize complicated business stakeholder relationships" (Chung, 2009, pp. 1). Many important similarities are shared with this article and our project. Both involve methods of synthesizing data from multiple sources into one compact and visually appealing segment to better suit the needs of those who will then make use of the information provided.

The article is centered around the purpose of accurately using business information for the benefit of one company to make calculated decisions for the future. Business intelligence (BI) is "…the product of acquisition, collation, analysis, interpretation and exploitation of business information" (Chung, 2009, pp. 2). Used correctly, BI is an efficient method of comparing one business to another, and is used to show possibilities for the future, such as identifying growing risks, competition strategies and important stakeholders. Our team will directly be collecting BI from other organizations through personal interviews in order to lay the basis of a partnership network for USZ.

Focus is then shifted towards the benefits of information visualization when combined with business information. Various approaches are explored, and the benefits and drawbacks to each are discussed. One major approach introduced is the "Knowledge Network," whereby metadata is gathered and then extracted into a spidering visual network for easy comparison between companies. Although this approach involves programming tools that perform automatic searches and storage into these network nodes, our main interest is in the visualization of the result, as it is very useful for identifying communications between different stakeholders.

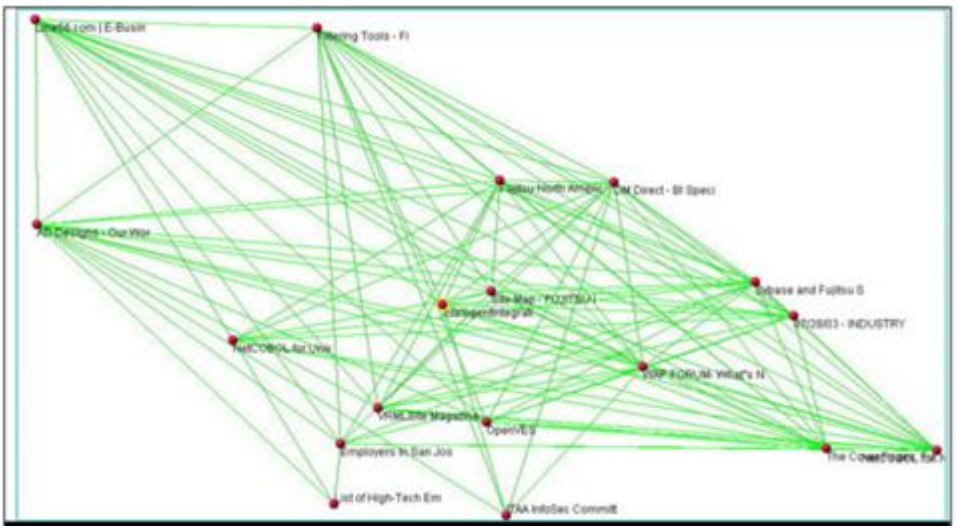


Figure 2. A Stakeholder Network of "Fujitsu Software"
*(*http://aisel.aisnet.org/cgi/viewcontent.cgi?article=1003&context=pajais*, 2009)*

The visual network of the chosen company in the article, "Fujitsu Software," proved helpful to many outside stakeholders as they could immediately see direct relations between the internal stakeholders, and further specific details (such as accessibility, reputation, and representation) about each node were displayed when clicked on.

The case study supported the idea that BI data visualization is an effective method which conveys accurate information, stating in their conclusion that stakeholder network visualizations "significantly outperformed a traditional method of BI analysis in terms of efficiency, information quality and user satisfaction" (Chung, 2009, pp. 1). Our project aims to use this knowledge to provide a helpful and visually appealing way of connecting various companies together to provide a useful and personalized network for USZ.

2.5 Summary

The ORL clinic within the University Hospital Zurich is seeking to expand their usage of different technologies relevant to creating accurate printed models of parts of the ear. Rapid prototyping technologies are already being used in this area of work. However, due to the immaturity of this application, there is little communication or cooperation between researchers on the subject. Thus, a great deal of networking, communication, and planning is required if these technologies are able to see usage in a practical setting. We have learned from our case studies that partnerships have successfully been made in the past to synthesize information from various sources together, making the adoption of desired manufacturing techniques a smoother process. Furthermore, it has been demonstrated that relevant business information displayed in an easily readable and visual manner greatly increases the satisfaction of those involved in making decisions for the future of their institutions.

Chapter 3 - Methodology

Our goal was to identify potential partners for a network of institutions which provide knowledge and services that would allow the University Hospital Zurich's department of Otorhinolaryngology, Head and Neck Surgery (ORL) to make use of additive manufacturing (AM) in their research. There were three primary objectives which we focused on toward achieving this goal:

1. Assess the ORL's prior knowledge of AM
2. Identify and interview institutions which can provide useful knowledge and services to the ORL
3. Consolidate the gathered information into a compact format for USZ members to pick up later for their use.

3.1 Assess prior knowledge

In order to better understand the needs of the ORL, we conducted interviews with as many ORL personnel as possible to ascertain their current knowledge on AM technology, as well as their goals and needs. An obstacle to this was that these medical professionals lead very busy lives, and it was somewhat difficult to schedule meetings within the time constraints of the project. In spite of this challenge, we successfully interviewed five people from a variety of different roles at the ORL, including medical researchers, doctors, and engineers.

The interviews were conducted informally, and generally lasted from 15 to 30 minutes. The brief, informal nature of the interviews made them easier to schedule, and allowed us to go "off script" if a conversational thread seemed likely to provide key information about the ORL or the current state of AM in medicine. Interviewees were asked to describe their role in the ORL, and how they thought AM could benefit their work, if at all. These questions allowed us to construct an overview of the needs of the clinic, and helped us to determine what types of information services would be most useful to the ORL. At the end of each interview, we asked whether there were any specific projects, organizations, or individuals which had done relevant work of personal interest to the interviewee. The names gathered from these internal interviews provided the starting point for building a broader network of AM service providers in medicine. For more information about the nature of the interviews, see the interview guide in Appendix A.

3.2 Identify and interview external institutions

This step represented the primary method of gathering information in this project. In order to begin, we had to create a preliminary list of organizations to interview. This list was assembled from a variety of sources, including from internal interviews and relevant research papers. One major way in which we gathered more contacts was by attending two events for medical professionals. The first was the ORL's own 100-year Symposium (https://usz-microsite.ch/100-years-orl/), which was attended by researchers from around the world to share recent work on a variety of topics in otorhinolaryngology. The other event which we attended was the 2017 MedTech Expo in Lucerne (https://www.visit.medtech-expo.ch/en/), an event focused broadly on connecting companies, clinics, and researchers within the medical community. One of the central focuses of the 2017 expo was AM.

Once we had identified potential interviews, we contacted them over email requesting an interview. These external interviews had to be particularly flexible, as the companies were spread over a large geographical range, with one interviewee being based in the USA and the rest scattered around Europe. In addition, the time constraints of the project made scheduling very tight, especially for institutions which we discovered toward the latter half of our time in Zürich. To navigate these issues, we allowed interviews to be done over the phone or with video conferencing software.

These interviews were conducted similarly to the internal interviews. We were interested in gaining a general overview of the interviewee's role in their organization, the capabilities of the institution, and what relevant work they had done in the past. See Appendix A for a more detailed overview of the interview process. Collectively, these questions were meant to help us understand how a partnership between each organisation and the ORL might work. What would the costs and benefits be?

Another vital resource gained from the external interviews was the names of other organisations of interest. We were able to employ snowball sampling from these interviews and build a much larger network of potential partners than the small list with which we started.

3.3 Consolidate and present gathered information

In order to most effectively present the data to our sponsor, we created a standardized data form that summarizes the capabilities of each institution, as well as additional notes on an *ad hoc* basis. Because we only interviewed nine institutions in person, we supplemented this data by creating additional data forms for institutions that we had learned about during this project, but did not have a chance to directly speak with a member. These supplemental forms include a note that the gathered information is not from interviews, and also include a list of sources (mostly weblinks). The empty forms can be seen in Appendix B. To lend more structure to this data, a list of tags was created to describe the various types of institutions. The tags are short textual descriptors that represent trends found among the organisations investigated. A table of the created tags can be seen in Appendix C.

Since the resulting mass of data was still somewhat cumbersome, we created a web app to help sort and visualize the data. The web app features an interactive network graphic of all the institutions interviewed, with edges in the network representing when one organisation directly referenced another one in an interview. It also allows the network to be filtered so that only organisations with a certain set of tags are shown, and includes all of the data contained within the forms.

Finally, in order to ensure the usefulness of these deliverables to our sponsor, we presented them to the ORL hearing mechanics research team of which Dr. Dobrev is a member. We then asked the entire team for feedback and recommendations on the data forms, tags, and web application, and took this into consideration in their development.

Chapter 4 - Findings

Through data collection, interviews, phone calls, and online investigation of medical researchers and industrial companies, our team has been able to draw a meaningful basis of discoveries to help reach our original goal. Our core findings for understanding the adoption of additive manufacturing (AM) into the University Hospital Zurich's ORL clinic are detailed below.

1. Many AM use cases which interest the ORL do not appear to be commercially available
2. There are groups that are trying to facilitate communication between researchers and the companies who supply AM technology
3. While the expansion of AM companies into the medical field is new, it is a rapidly expanding space
4. Experts who work with AM in medicine can provide rich information about the current ecosystem around the technology

4.1 Many AM use cases which interest the ORL do not appear to be commercially available

Since the ultimate purpose of this project is to enable the ORL to begin to incorporate AM in their work, we set out to determine what specific uses of the technology interested the researchers there, and how they could access the necessary services for these uses. Every ORL member whom we interviewed was able to suggest a list of potential applications to their work, but none of them are actively pursuing projects which make use of these applications, with one exception-- the clinic is already making use of 3D-printed temporal bone models from the company Phacon for training surgeons.

There were a few applications which repeatedly came up in our internal interviews as being of great interest to the clinic. Researchers Dr. Ivo Dobrev and Dr. Jae Hoon Sim both said that one of the primary applications which interested them was the creation of functionally accurate models of heads, temporal bones, and the ear itself which they could use for experiments on hearing mechanics in place of cadaver parts, Dr. Dobrev emphasizing his interest in this technology over a number of interviews.

While there are many research projects investigating 3D-printing of various types of accurate models of the ear and temporal region (see Section 2.2 of this report), we were unable to identify any external institutions which aimed to make these sorts of models commercially available. While it is possible that such an effort exists and we simply failed to identify it, it seems likely that, because of the lack of maturity of medical AM in general, no companies have yet endeavored to develop this niche category of products.

More applications which were brought up by multiple ORL personnel and which we could not locate commercially include the creation of tympanic membrane grafts and ossicular replacement prostheses. As before, these processes have been realized successfully in various research settings, but only using extremely specialized equipment and materials which do not appear to be readily available commercially.

Of course, the ORL is a research institution, so this lack of commercial availability is not necessarily an obstacle. It simply suggests that to apply AM in these ways would likely require collaboration with other research groups that are interested in similar work. Moreover, there is

still a wealth of applications of AM in medicine which are much more easily accessible, and could be equally good candidates for use in the ORL's future research projects.

4.2 There are groups that are trying to facilitate communication between researchers and companies who supply AM technology

AM is still a very young technique, originating only around 30 years ago when the first fused deposition modeling (FDM) machine was created by S. Scott Crump in 1988, and was then released and mass marketed by his company Stratasys in 1992 (U.S. patent 5121329, 1992). Since then, many companies have been trying to refine 3D printing to better suit commercial purposes. As such, there has only been a limited amount of time for the industrial technique to acquire proper footing, resulting mainly in a key division between two groups using the technology: researchers trying to find new ways to use AM, and industrial companies who supply and offer the technology for refined and specific work.

There is evidence that the lack of communication about AM is well-known between the two groups trying to make use of the technology. Our team discovered during the Swiss MedTech Expo that one business is directly addressing poor networking between AM companies and potential customers. The AM Network (https://www.amnetwork.ch/en/) was launched at the beginning of this year, and our team asked the president of the business, Markus Baertschi, questions about his desire and goals for this website. Mr. Baertschi informed our team that the AM network attempts to address the lack of communication in the field of AM, and wishes to create a formal collaboration between businesses and contractors for people such as USZ to get help towards the right resources.

There are government-funded events and businesses that are attempting to address this communication gap as well. The AM Network describes itself as "an initiative supported by the commission of technology and innovation (CTI) in the NTN (Nationale Thematische Netzwerke) program." (https://www.amnetwork.ch/en/). There are a large number of funding groups from many different countries that reach out to medical institutions to help promote information sharing (Huang, 2014).

One factor towards stifled communication in the medical field may be the rapid growth rate of AM. It is possible that companies are not cooperating as efficiently as they could be because the potential of AM is growing vastly every year, and other factors such as price per product, speed of production, and ease of use are improving so quickly that it is difficult to keep up with where the technology is in the present. Below is a graph displaying the projected rate of growth of AM.

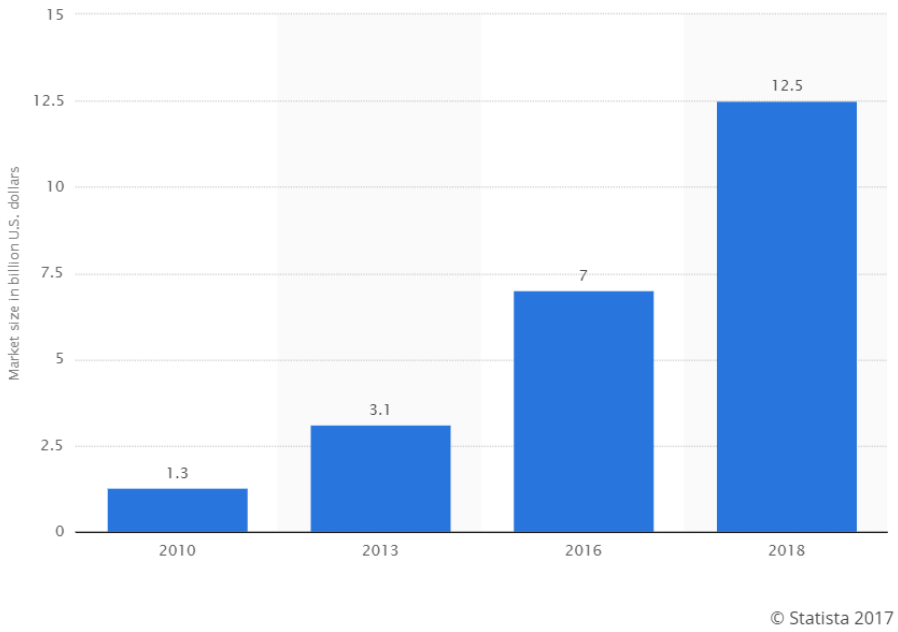


Figure 3. Projected global AM market size from 2010 to 2018 (in billion USD) (2017) (https://www.statista.com/statistics/284863/additive-manufacturing-projected-global-market-size/)

As displayed above, the market size of the technology has more than doubled every 3 years in the past decade, with it projected to nearly double in just two years between 2016 and 2018. This growth rate may be so big that companies are not able to adapt to the changes that are being imposed on them by their competitors, thus they are focusing purely on refining the product themselves.

Despite this lack of consistent communication in AM, researchers appear to be more involved in expanding networks for partnerships. During the Swiss Medtech Expo, when various exhibitors were asked about their knowledge and/or partnerships of other AM businesses, a representative of FHNW (a life sciences university focused on medical technology) stated that they were in close co-operation with an industrial company called Medtech, but when the same question was asked to a person at Materialise (a large contract-based AM provider), they indicated they were unsure of other companies with similar lines of work and could not list any competitors. It appears that a potential obstacle for communication across the topic of AM is that researchers are willing to contact both institutions and other researchers, whereas institutions are focused solely on finding customers for their product, and if they are in close contact or partnerships with other institutions, this information is hidden well from customers.

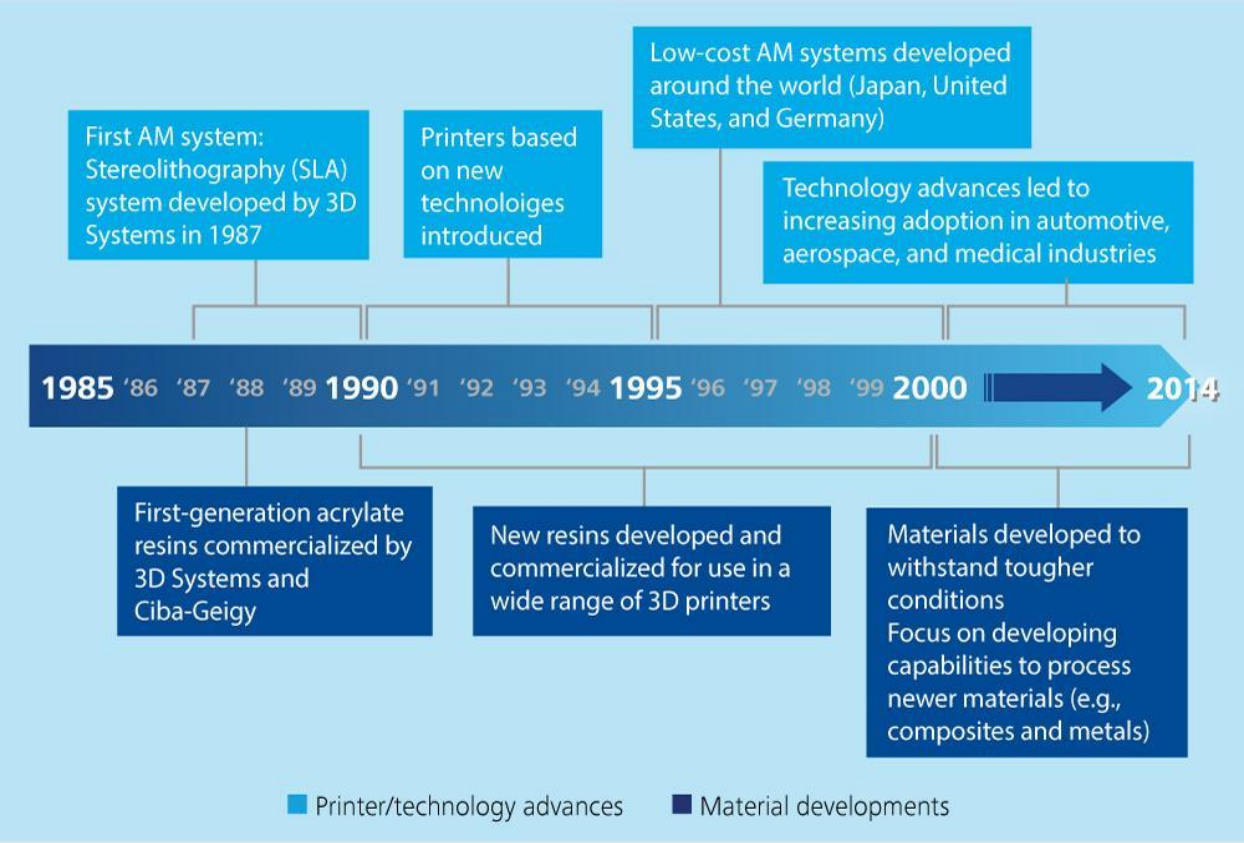
From this information we can detail that places involved in the usage or research of AM are aware of the fact that there has been poor conversation among groups and there is room for improvement, which will hopefully lead to more collaboration and business agreements between researchers and product providers.

4.3 While the expansion of AM companies into the medical field is new, it is a rapidly expanding space.

While attending MedTech in Luzern, our team had the opportunity to speak to a multitude of AM companies. We noted that the medical divisions of these companies had only

begun recently. This appears to be a primary reason for the communication gap earlier mentioned in finding 4.2, as many companies have only just begun exploring new applications of AM as it applies to medicine. This can also be observed in the history of AM, as shown below.

Figure 3. Evolution of additive manufacturing technology



Source: Deloitte analysis; Wohlers Associates, *Additive manufacturing and 3D printing state of the industry*, 2012; The University of Texas at Austin, "Selective laser sintering, birth of an industry," December 7, 2012, http://www.me.utexas.edu/news/2012/0712_sls_history.php, accessed January 25, 2014.

Graphic: Deloitte University Press | DUPress.com

Figure 4. Brief History of AM
(https://dupress.deloitte.com/content/dam/dup-us-en/articles/the-3d-opportunity-primer)

In our interview with Materialise GmbH, a major AM company based out of Belgium, we discovered that while their company is over 25 years old, they only recently expanded into the medical field. Carina Wiederer, an engineer in their medical printing department noted that the company is now working to expand its horizons, and is focused on working with clients towards achieving their individual goals. Thus even one of the first companies in the AM space is only just recently expanding into medical applications.

Furthermore, we spoke to Ralf Schindel, the CEO of Prodartis AG, a Swiss plastic fabrication company that does contract work for their clients. Prodartis has only existed since 2014, and is now one of the prominent plastic fabrication companies in Switzerland. They are

currently focusing on customizable implants and surgical tools, but they are looking into new applications for the technology.

We also spoke to Dominique Beuchat, the CEO of 3D Precision SA, a metallic 3D printing contractor based in Delemont, Switzerland. 3D Precision SA use a novel technique of selective laser melting (SLM) to create metallic parts. Recently, they opened a medical tooling department, and are still a very small business, as mentioned in their interviews.

While these companies are very new in the medical field, each interviewee expressed an interest in expanding their horizons in the field. This shows that while the technology that the ORL team is seeking is not available at the moment, there is immense potential in the research and applications utilized by companies in AM.

4.4 Experts who work with AM in medicine can provide rich information about the current ecosystem around the technology

The results of our interview process indicated that there is a great deal of knowledge to be gained by consulting with a relatively small number of medical experts who are familiar with AM. More specifically, these experts are often knowledgeable about a variety of AM service providers and are willing to freely provide this information. We were able to construct a large network of a diverse variety of companies, research groups, and applications by simply asking every interviewee whether they knew any other institutions which were doing relevant work. Every interview with a university or hospital (including USZ itself) led to at least one previously unknown company, as can be seen in the network representation below. AM Network, a young government-sponsored company which specializes in connecting AM service providers to clients, mentioned several institutions in the interview and told us how to access an even longer list of institutions on their website. Figure 4.2 below illustrates the progress made with snowball sampling (some institutions were mentioned but were not further investigated by this project, and those are absent from the graph).

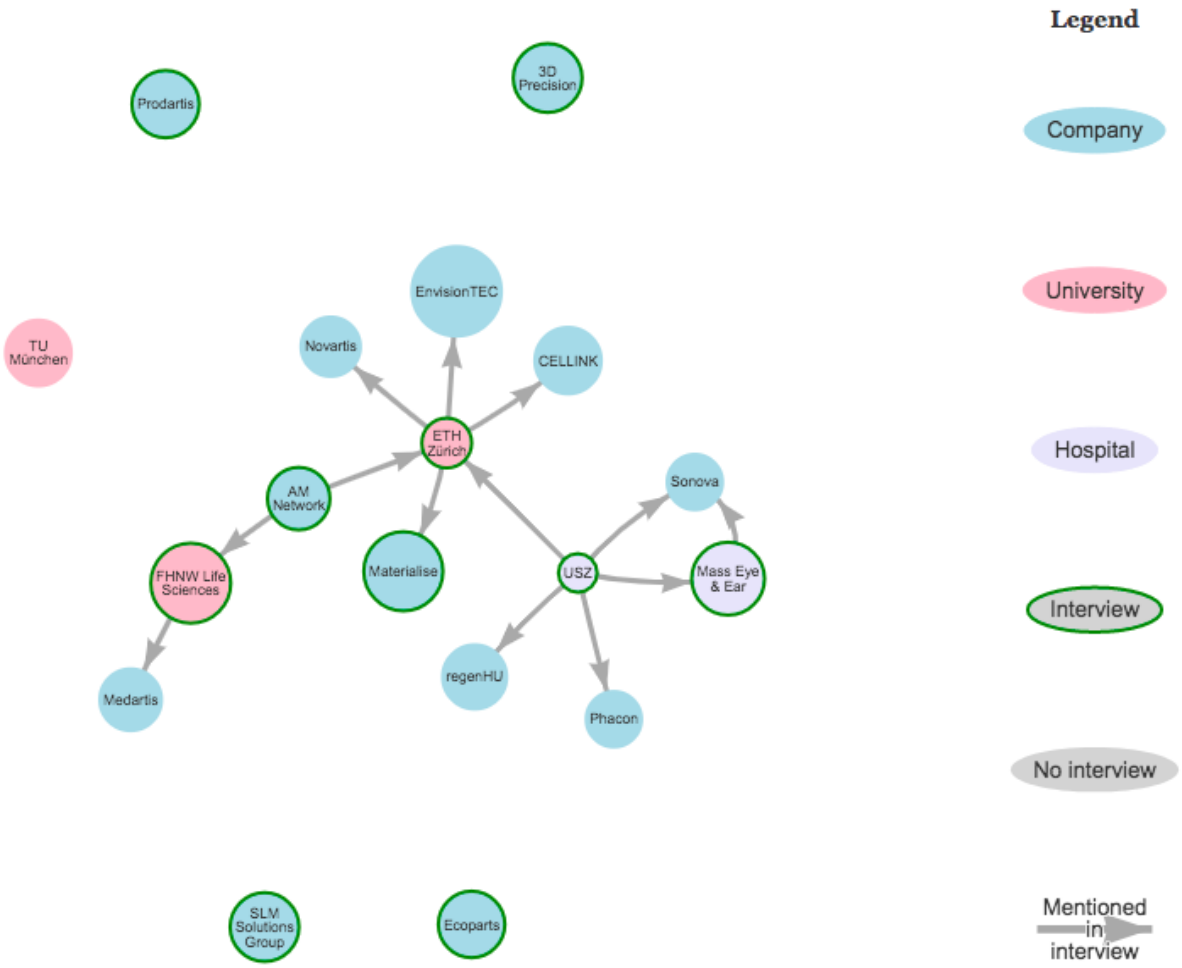


Figure 5. Interview Sampling Network

By contrast, interviews with companies that were new to medical applications, such as Prodartis AG, 3D Precision SA, and even the prototyping department of Materialise GmbH did not lead to any new contacts, possibly because these people were less familiar with the specific needs of medical applications. These meetings still revealed some application areas of AM which were previously unknown to us; Ecoparts AG, for instance, told us that they had done jobs printing customized surgical tools, and Materialise showed us multicolored translucent models intended for educational use or surgical prep, but almost all of our interviews with contractors were dead ends in terms of discovering new institutions to investigate. Another obstacle was that companies may have been reluctant to acknowledge their competitors. In an interview, Materialise GmbH openly admitted as much.

Focusing on communication within the research community would ultimately be much more rewarding than reaching out to most companies in order to understand the currently available resources and applications for AM in medicine.

Chapter 5 - Recommendations

Using the findings we have consolidated from our previous chapter, our team can suggest three key recommendations for our sponsor and his team at University Hospital Zurich (USZ).

1. Tap into the knowledge of medical experts
2. Contact AM Network
3. Stay up to date with developments in additive manufacturing (AM)

5.1 Tap into the Knowledge of Medical Researchers

There are many possible applications of AM technology in medicine, many of which may require in-depth technical knowledge to properly implement. While this project aims to present a starting point for accessing these applications, it is likely that more information will need to be gathered before they can be fully utilized. To this end, we recommend that when the USZ requires further knowledge about a certain application or technique of AM, the first group to be contacted should be research personnel at hospitals or universities with relevant experience.

More specifically, there were three research institutions which we had a chance to interview: ETH, FHNW, and Massachusetts Eye & Ear. As noted in section 4.4 of this report, we had very productive conversations with these organisations, but while these interviews yielded a tremendous amount of information, there were some difficulties in communicating due to the large gap in levels of technical knowledge between the interviewer and interviewee. As a result, we believe that research personnel at the ORL would benefit greatly from contacting these researchers directly. More specific contacts for these locations are available in the data forms which we are providing to the ORL.

In addition, there are some other academic institutions which we did not have a chance to interview that may be of interest to the ORL. One of these in particular is the TU München Institute of Microfabrication and Medical Devices, the department which produced the paper by Kuru et. al entitled “A 3D-printed functioning anatomical human middle ear model.” In fact, since many academic papers include contacts for the authors, any of the technical works cited in the background section of this paper could potentially provide access to researchers who would have relevant technical knowledge.

While conversations with commercial AM service providers may still be important, these sorts of contacts should be considered to be of secondary importance, and they will likely have little value until after the technical details of a desired application are thoroughly understood.

5.2 Contact AM Network

One of the central problems which this project aimed to address is the lack of communication between various stakeholders in medical AM technology. Out of all the institutions which we interviewed, the AM Network stood out as the one organisation which intended to directly address this same obstacle.

Many of the company’s services can be accessed via its website, which provides a wealth of information about recent developments in AM technology, completely free of cost. In addition to displaying information about upcoming expos, symposiums, and workshops related to AM, the website also provides a searchable database of all of its partner institutions, and gives

examples of collaborations formed with the help of AM Network. Based on our experiences, the owners of the company are quick to respond when contacted, and can provide very detailed and helpful information. Registering as a part of the network is also an option, which would provide various benefits depending on whether the USZ chose to register as a company or a research institution.

AM Network is still a very young company, but is clearly growing quickly; from their recent launch of the company in January 2017, they already have 27 members, with over 3 companies joining the network per month on average. In addition, the group of members organisations represents a fairly balanced mixture of research institutions and AM service providers; of their 27 members, 12 are primarily concerned with research. Out of all the institutions investigated during this project, no other group brings together such a diverse body of expert knowledge, and no other group has such a strong focus on promoting collaboration.

5.3 Stay up to date with developments in AM

It is important that the hearing research team stays up to date with developments in AM. As noted in finding 4.3, most AM companies have only recently begun entering the medical field. For this reason, the technology is very new, and in order to be used in the applications that the USZ hearing research team is seeking, the technology will require some further technological development.

However, there are constant discoveries and applications being implemented worldwide. For example, in the United States, the Mass Eye and Ear hearing research team is doing revolutionary work in conjunction with the Lewis 3D printing group at Harvard, and by doing so, is expanding the horizons of AM.

There are several concrete ways that Dr. Ivo Dobrev and his team can stay up to date with developments in AM, the most important of which is joining the AM Network, and ensuring the team attends as many of their conferences as possible. The team schedules events during their weekly team meetings held on Thursdays. In advance, Dr. Ivo Dobrev can inform the team of an upcoming AM Network conference, and gauge the interests and availabilities of the team. By doing so, the ORL research team will be directly involved with AM companies and institutions in Switzerland, directly informing them of their advancements on a consistent basis. Furthermore, the research team should make a point of attending the MedTech exposition every year, as it is run with the purpose of exploring the current state of AM technology.

Additionally, it is important that the research team continues monitoring medical journals for any research pertaining to AM. Although they are already subscribed to a multitude of medical journals, as identified in our baseline assessment, we recommend adding *ScienceDirect* (a database of journals), *Additive Manufacturing*, and the *American Journal of Medical Technology* to their list of journals. These were the journals we found most helpful throughout our project, and will allow the team to effectively monitor developments in AM.

Staying up to date with developments also allows the added benefit of partnership opportunities. Should the hearing research team discover a specific company or institution that has begun working on an area of AM that is of particular interest to them, they will be able to reach out, and potentially partner with them. As the team is specifically interested in working with other companies and institutions, this will be of great benefit to them.

Chapter 6 - Conclusion

Additive Manufacturing (AM) is a rapidly expanding field, with growing applications in medicine. The University Hospital Zurich (USZ)'s hearing research team tasked our group with creating a network of institutions which provide the processes and materials necessary to make use of the applications of AM relevant to their research. To do so, we created three primary objectives to successfully accomplish this: ascertain existing knowledge of AM at USZ, and find what further information is needed to make use of it, find institutions that can provide necessary skills and resources for the adoption of new AM technologies at USZ, and finally create a database that provided accurate and useful information for submission to USZ.

Our team utilized data collection, interviews, phone calls and online investigation of medical researchers and industrial companies to draw a meaningful basis of discoveries to achieve our goal.

The team discovered the following:

- Many AM use cases which interest the ORL do not appear to be commercially available
- There are groups that are trying to facilitate communication between researchers and the companies who supply AM technology
- Although the expansion of AM companies into the medical field is new, it is a rapidly expanding space with growing potential
- By tapping into the knowledge of experts, a detailed view of a variety of different AM technologies and services becomes available

One of the major challenges faced by our team was the limited technical knowledge necessary to speak to medical professionals regarding this topic. As it is such a revolutionary technology, it is dominated by those with PhDs in the field, whose knowledge far exceeded ours. Furthermore, our team had limited time to set up interviews, as we were only able to do so once arriving in Zurich. Scheduling interviews prior to arriving may have proved useful as the team was only able to speak to institutions and companies that were available during our time in Zurich.

Through the incorporation of our interactive web application, as well as the data forms, we believe the discoveries that our team made can provide the hearing research team with a foundation for developing relationships with potential partners in the field of AM. By doing so, we hope that they will be able to make great strides in the field of otology.

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Appendices

Appendix A - Interview Questions

Below is a guiding structure of questions that our team used during interviews. Due to the broad nature of our goal, our interview questions were subsequently semi-structured and consisted mainly of a guideline of certain points to address. Every interview, whether it was internal or external to the ORL department, varied depending on specific topics of interest for the interviewee.

Internal (USZ) Questions

1. Can you briefly describe your role in the ORL department?
2. Are you aware of any helpful use cases for Additive Manufacturing relative to your work?
3. Do you envision AM having a significant future role in the clinic?
4. Are you aware of any groups currently supplying or using AM?

External (Company) Questions

1. Can you briefly describe your role within the company?
2. How long has your company been using AM/When was your company founded?
3. What medical applications of AM do you supply, if any?
4. What specific services do you offer for customers wishing to make use of AM?
5. Have you been in partnerships or performed research with any outside places in the past?

Appendix B - Empty Data Form

Name:	**Description**
HQ Location:	
Interview date (No Interview)	
Services Offered	**Additional Notes**
•	•
Tags:	
Contacts (References)	
•	

Table B.1: Data Form (parenthesized text is for institutions with no interviews)

Appendix C - Tags

Tag name	Description
3D Printing	Sells 3D printing machines to customers
Biomaterials	Provides services related to biomaterials
Company	Is a commercial enterprise
Consulting	Provides individualized consulting information about AM
Contract Printing	Will print parts on a contractual basis
Hospital	Is a hospital
International	Has international presence (i.e. has offices in multiple countries)
European	Is headquartered in Europe
Metals	Provides services related to metal printing
Plastics	Provides services related to plastic printing
Swiss	Is headquartered in Switzerland
University	Is a university

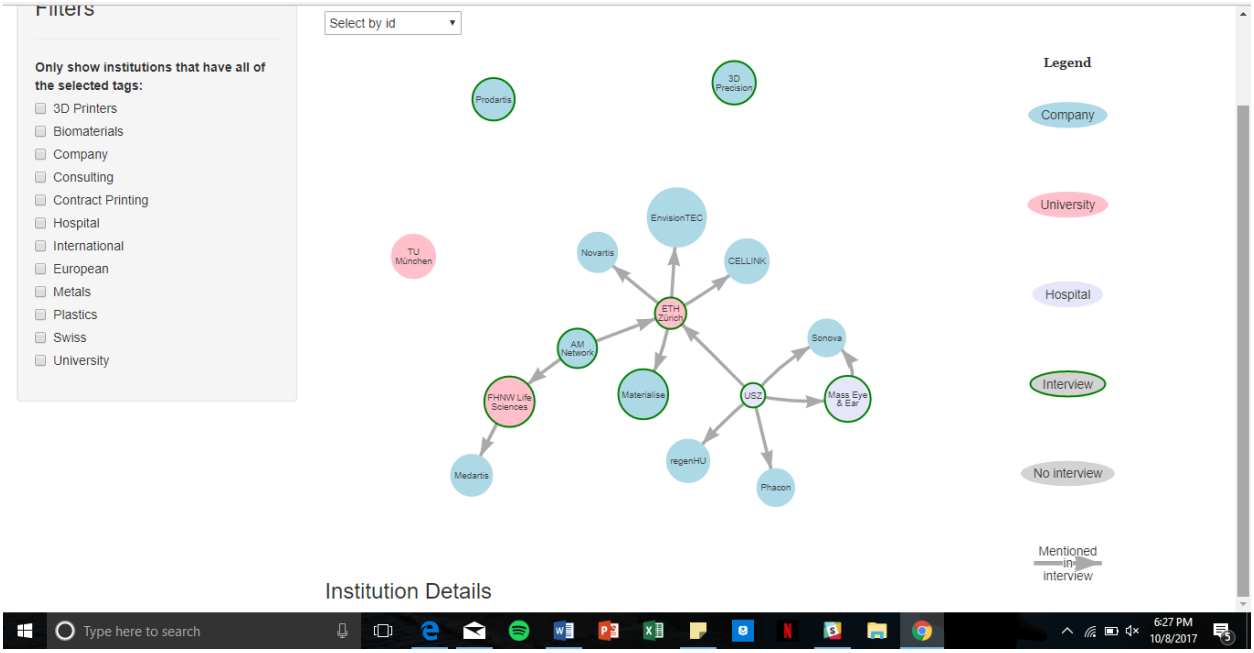
Table C.1: Tags and Descriptors

Appendix D – Web App Use Case

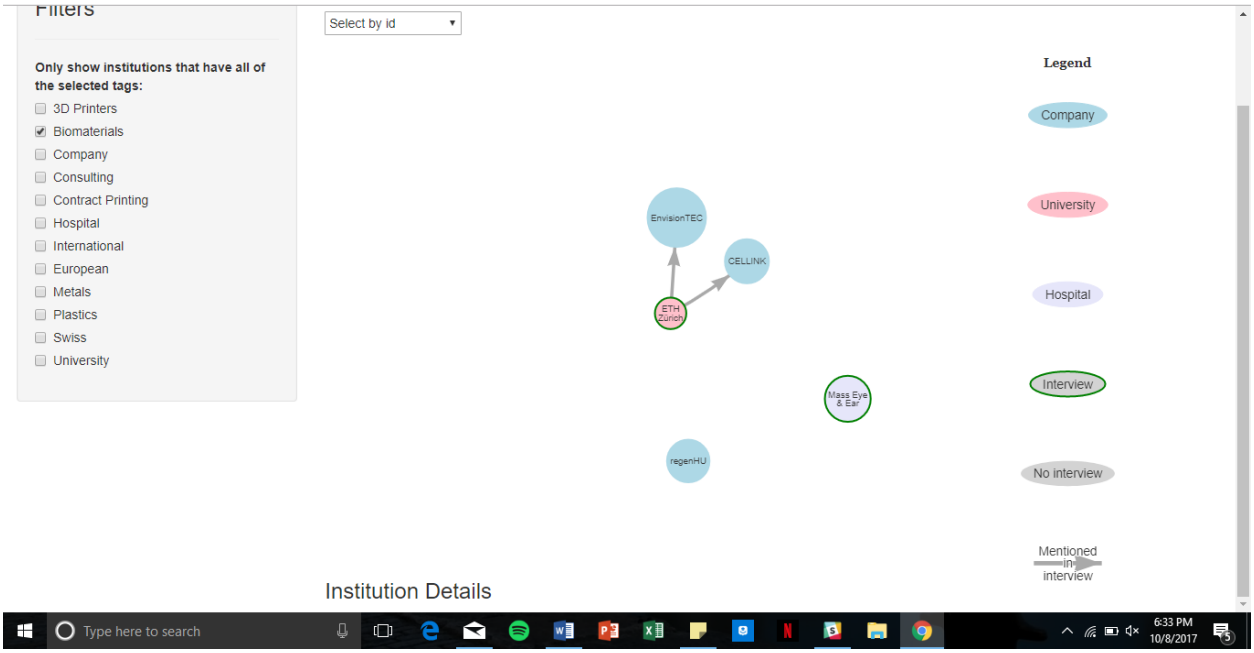
Example use of web application:

Example: USZ is interested in a bio compatible model of the ear. Also, they want a specialized order, and are interested in working hands on with the company to produce the model to their specific needs.

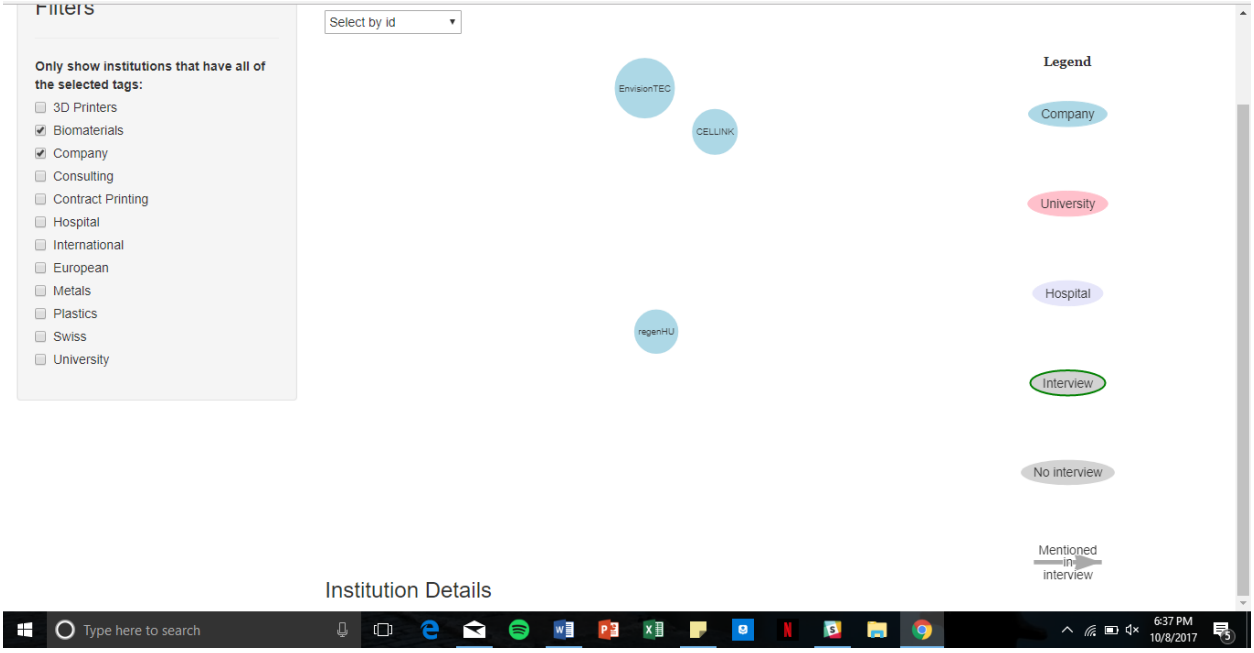
Step 1: Access database online



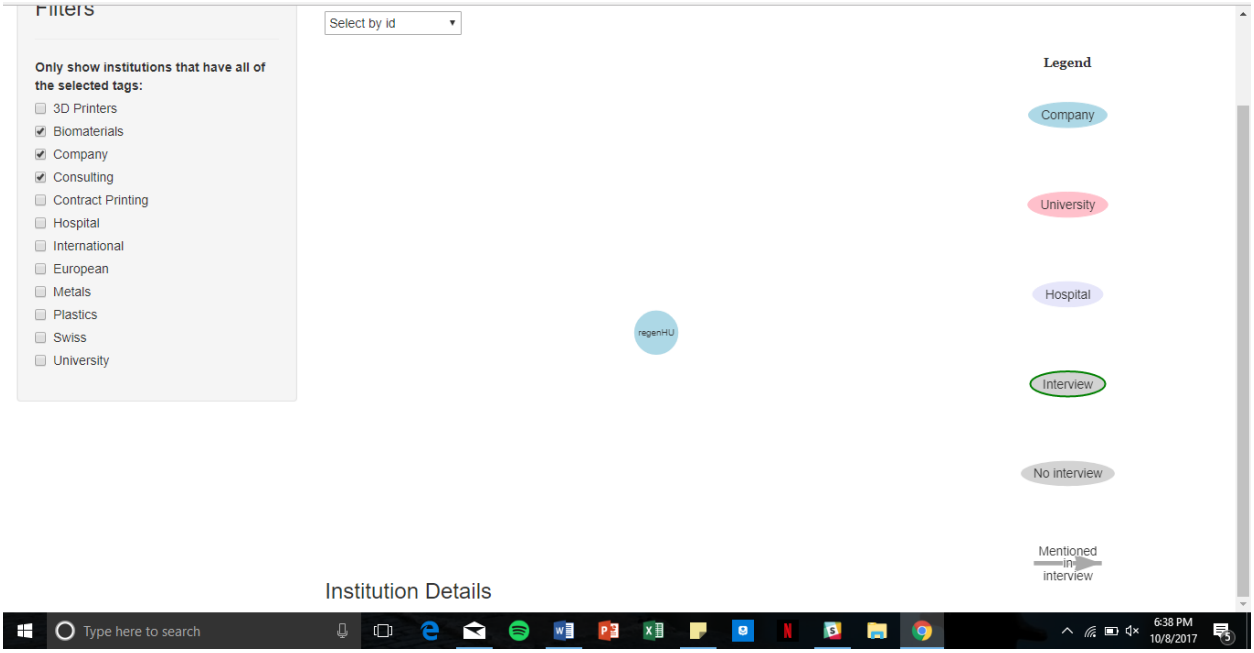
Step 2: Since USZ is interested in biocompatible models, they should select the biomaterials tag, which narrows down the visualization to companies that do work with biomaterials.



Step 3: Since USZ is interested in working with a company, they should select the company tag.



Step 4: Since USZ is interested in personally working with a company, they should select the consulting tag.



Conclusion: For this particular project, RegenHU meets the desired criteria for USZ's project. Further information can be accessed by scrolling down to reveal details such as specific services offered and contacts to the company. This is one example of many different scenarios to find a specific AM provider to suit a researcher's needs.

Institution Details

Name: regenHU Ltd

HQ Location: Villaz-Saint-Pierre, CH

No interview

Services Offered

- Biomaterials for printing specific models such as extracellular matrices
- Able to 3D print stem cells and other specific biocompatible objects
- Different 3D printers for sale, depending on requirements

Tags: Biomaterials; Company; Consulting; European; International; Swiss

References

- Website: www.regenhu.com
- Main Contact Email: info@regenhu.com

Description

3D bioprinting machine provider, including various biomaterial supplies

Additional Notes

- Full list of partners and customers available on website
- Published software tools for creating three-dimensional structures like tissue and bones
- Worked in the past with companies to create educational models

Appendix E – Data Forms

Name: 3D Precision SA	**Description**
HQ Location: Delémont, CH	Mechanical/metallic 3D printing contractor
Interview date: 2017-09-19	
Services Offered	**Additional Notes**
• Consulting towards designing 3D models using rendering programs • Manufacturing parts using Selective Laser Melting (SLM)	• Created in January 2014 • Focused on creating metallic parts from cars and planes, but also have a separate section dedicated to medical tools. • Very small business currently
Tags: Company; Contract Printing; European; Metals; Swiss	
Contacts	
• Website: www.3dprecision.ch • Main contact email: info@3dprecision.ch	

Name: AM Network	**Description**
HQ Location: Zürich, Switzerland	Collaborative, government funded effort to connect AM providers and potential AM customers together through social networking
Interview date: 2017-09-19	
Services Offered	**Additional Notes**
• Private and personal communication help for finding business partners • Free membership on website for easy contacts and information about events	• Very new group (Began Jan-Feb 2017) • Already has over 25 registered organizations on their website • Markus Baertschi, (President of AM Network), saw gap between AM providers and potential customers and wanted to close that communication gap

Tags: Company; Consulting; European; Swiss
Contacts
• Website: https://www.amnetwork.ch/en/ • Main contact email: contact@amnetwork.ch

Name: CELLINK AB	**Description**
HQ Location: Sweden	Bioprinting supplier specializing in microfabrication printers
No interview	
Services Offered	**Additional Notes**
• Bioprinter with wide range of potential materials for usage • 'BioInks' - hydrogel biomaterials for printing small biological components such as extracellular matrices, nanocellulose and collagen	• Multiple distributors across different countries • Founded January 27th, 2016 • Large expansion rate considering the age of the company • Claims to be the first bioink company in the world • Only offers 2 printers currently, 'INKREDIBLE' and 'INKREDIBLE+', but they are highly specialized • Won startup of the year in 2016, multiple other awards since foundation
Tags: 3D Printers; Biomaterials; Company; European; International	
References	
• Website: www.cellink.com • Contact email: sales@cellink.com • Contact site: www.cellink.com/contact/	

Name: Ecoparts AG	**Description**
HQ Location: Rüti, CH	AM contractor focused on using metals through SLM printing

Interview date: 2017-09-19	
Services Offered	**Additional Notes**
• Printing specialized tools and components from titanium, steel, aluminium, etc. • 'Company screening' service, including identification of AM potential, risks and opportunities. • Repairs and material changes for existing products	• Strong impression during interview, very open and friendly • Very experienced and knowledgeable about their work • Multiple reports published • One of the few companies using lightweight metals such as titanium and aluminium
Tags: Company; Consulting; Contract Printing; European; Metals; Swiss	
Contacts	
• Website: http://www.ecoparts.ch • Main contact email: info@ecoparts.ch	

Name: EnvisionTEC GmbH	**Description**
HQ Location: Gladbeck, DE	Company selling various 3D printers for multiple applications, including desktop printers and bio-plotters
No interview	
Services Offered	**Additional Notes**
• 3 core categories served, medical, industrial and professional • Provides leading biofabrication printer • Multiple materials offered, including microfabrication plastics • Offers detailed printers for specific applications such as hearing aids and bones	• Founded in 2002 • Sells more than 40 different kinds of printers • Provided service in 66 countries • Multiple published case studies available on website • Existing Patents and applications under their name • Originates in America (Dearborn, Michigan)
Tags: 3D Printers; Biomaterials; Company; European; International	
References	

- Website: www.envisiontec.com
- Contact Site: https://envisiontec.com/contact-us/

Name: ETH Zürich	**Description**
HQ Location: Zürich, CH	A research group at ETH which specializes in creating biocompatible implants. Two research groups there are of interest, the Tissue Engineering and Biofabrication Group, and the Product Development Group
Interview date: 2017-09-06	
Services Offered	**Additional Notes**
• No services per se, but they have access to a variety of sophisticated 3D printing techniques including electrospinning and 2 photon polymerization. These assets could prove helpful if a research partnership were formed.	• Interviewed the Biofabrication Group but not the Product Development group • The Biofabrication group has done substantial impressive work toward biofabrication of cartilage implants that allow living tissue to regrow • Most Biofabrication research is focused on creating implants rather than on creating functional models. • The interviewee asked not to have their name or contact information included in this report, but indicated that the group would be more willing to communicate with a researcher from the ORL than with an undergraduate student. • The product development group was present at Medtech and is a part of AM Network
Tags: Biomaterials; European; Swiss; University	
Contacts	
• Website: http://www.biofabrication.ethz.ch/ • Group member info: http://www.biofabrication.ethz.ch/the-group/people.html	

Name: FHNW Life Sciences	**Description**
HQ Location: Muttenz, CH	

Interview date: 2017-09-19	A department of a major university based in and around Basel. AM in medicine is one of their active research areas
Services Offered	**Additional Notes**
• Contract printing of biocompatible metallic structures	• Spotlighted building scaffolds that could replace damaged bone • Interviewee mentioned that new bone tissue could grow over the scaffolding • Would not disclose information about who their clients were, but did mention that they worked with both research institutions and commercial operations • Their metal structures can be sandblasted, making them very smooth • As a research institution, they publish a lot of papers, which could make them a good academic partner • Strongly connected with Medartis
Tags: Contract Printing; European; Metals; Swiss; University	
Contacts	
• Website: https://www.fhnw.ch/de/die-fhnw/hochschulen/lifesciences	

Name: Massachusetts Eye & Ear	**Description**
HQ Location: Boston, MA, USA	Specialized hospital focused on ophthalmology and otolaryngology research and medicine.
Interview date: Interview 1: 2017-09-01 Interview 2: 2017-09-20	
Services Offered	**Additional Notes**
• Noteable success in treatments for difficult ORL diseases and large contributions to research in the area. • Research and clinical training for audiology	• MEEI mainly uses 3D printing for taking impression scans to create accurate measuring and alignment • Closely associated with Harvard • First Interview: ○ Exclaimed there is “Definitely a place for it” [Additive Manufacturing]

	○ Mentioned expense costs and drawbacks to temporal bones, which AM could easily solve ○ Cultural/Religious obstacles related to temporal bones (eg desecrating a body) • Second Interview: ○ Focused on 3D printed tympanic membrane grafts ○ For AM to be useful in the future, scaffolding needs to be compatible and replaceable with existing ear tissue ○ All printing is done by Lewis Research group at Harvard
Tags: Biomaterials; Hospital	
Contacts	
• Website: http://www.masseyeandear.org/	

Name: Materialise GmbH	**Description**
HQ Location: Leuven, BE	Major additive manufacturing company which mostly does contract printing.
Interview date: 2017-09-19	
Services Offered	**Additional Notes**
• Printing of a provided parts file out of a variety of materials (mostly plastics, and including many colors and textures) • Imaging of a physical model in order to create this parts file	• Interviewed at Medtech Expo in addition to email correspondence • Interviewees at Medtech noted that the company does a lot of research work in AM to push the boundaries, and they are willing to work closely with their clients toward achieving their goals • The company is 27 years old, making it one of the first in AM. • Partnered with HOYA to create customized eyewear • They have offices in many countries including Germany, France, and Switzerland.
Tags: Company; Consulting; Contract Printing; European; International; Metals; Plastics	

Contacts
• Website: http://www.materialise.com/

Name: Medartis AG	**Description**
HQ Location: Basel, CH	AM contractor focused on cranio-maxillofacial and hand surgery implants
No interview	
Services Offered	**Additional Notes**
• Multiple specific metallic structures for supporting fractures and damaged bones • Focused on hands, wrists, elbows, feet and skull (including cranium, midface and mandible) • Accurate screw and component measurements suited for each patient	• Originated in 1997, now a 20 year old company • Started with 6 employees, now over 400 worldwide • Partnered with IBRA (International Bone Research Association) (www.ibra.ch)
Tags: Company; Consulting; Contract Printing; European; International; Metals; Plastics; Swiss	
References	
• Website: http://www.medartis.com/ • Main Contact Email: info@medartis.com	

Name: Novartis International AG	**Description**
HQ Location: Basel, CH	Science based healthcare company focused on innovating new medical procedures and products
No interview	
Services Offered	**Additional Notes**
• Affordable medicines • Eye care devices • Rare disease treatment	• Created in 1996 • Over 50 marketed medical products • Large biomedical research division • Publications on work accomplished

• Partner collaboration	
Tags: Company; European; International; Swiss	
References	
• Website: www.novartis.com • Main phone contact: (+41 61 324 11 11) • Contact site: https://www.novartis.com/about-us/contact	

Name: Phacon GmbH	**Description**
HQ Location: Leipzig, DE	3D printed life models and simulations for education and business
No interview	
Services Offered	**Additional Notes**
• Accurate educational models featuring realistic hard and soft materials. • Specific ENT division, providing models for temporal bones, sinuses, throats, etc. • Models for heads, spines and vascular practice models • Can 3D print a patient with the help of MRI, CT or DVT scans	• Already in communication with the ORL clinic at USZ • Founded on April 27th, 2007 • Updated list of events that the company is appearing at • Provide virtual assistance with models that have been purchased
Tags: Company; European; International; Plastics	
References	
• Website: www.phacon.de • Main Contact Email: info@phacon.de	

Name: Prodartis AG	**Description**
HQ Location: Appenzell, CH	Plastic fabrication company for contract work
Interview date: 2017-09-19	

Services Offered	Additional Notes
• Laser sintering production for chosen models desired. • Price quotes on STL files • Specific Medical category of printing work	• In terms of medical applications, Prodartis focuses on customizable implants and surgical tools • Similar to Materialise in terms of services offered, but focused more on plastics than metals
Tags: Company; Contract Printing; European; Plastics; Swiss	
Contacts	
• Website: http://www.prodartis.ch/ • Main contact email: info@prodartis.ch	

Name: regenHU Ltd	**Description**
HQ Location: Villaz-Saint-Pierre, CH	3D bioprinting machine provider, including various biomaterial supplies
No interview	
Services Offered	**Additional Notes**
• Biomaterials for printing specific models such as extracellular matrices • Able to 3D print stem cells and other specific biocompatible objects • Different 3D printers for sale, depending on requirements	• Full list of partners and customers available on website • Published software tools for creating three-dimensional structures like tissue and bones • Worked in the past with companies to create educational models
Tags: 3D Printers; Biomaterials; Company; Consulting; European; International; Swiss	
References	
• Website: www.regenhu.com • Main Contact Email: info@regenhu.com	

Name: SLM Solutions Group AG	**Description**
HQ Location: Lübeck, DE	

Interview date: 2017-09-19	International company focused on business, learning and provisions for SLM printers
Services Offered	**Additional Notes**
• SLM printers and other specialized machines such as vacuum casters available for purchase • Training workshops to teach about how to use printers	• Worldwide span of service and outposts, with contacts in over 40 countries • Successful in creating dental tooth implants • Large support network including job offers and events • Marketing for SLM printers began in 2000, but has earlier history such as refining metals in the UK and starting the company Mining and Chemical Products ltd (MCP)
Tags: 3D Printers; Company; Consulting; Contract Printing; European; International; Metals	
Contacts	
• Website: https://slm-solutions.com/ • Main contact email: info@slm-solutions.com	

Name: Sonova AG	**Description**
HQ Location: Stäfa, CH	International hearing aid supplier, giving customer driven hearing solutions
No interview	
Services Offered	**Additional Notes**

• Provides various patient specific hearing aids
• Cochlear implants
• Access to hearing aid network through AudioNova
	• Began in 1947
	• Sponsors charity “Hear the World Foundation”
	• Currently uses AM to create unique and patient specific shapes for hearing aid fitting
	• Has 5 business brands currently:
	  ○ Phonak
	  ○ Unitron
	  ○ Hansaton
	  ○ Advanced Bionics (cochlear implants)
	  ○ AudioNova

Tags: Company; Consulting; European; International; Swiss	
References	

- Website: www.sonova.com
- Contact site: https://www.sonova.com/en/contact-us

Name: TU München	**Description**
HQ Location: München, DE	Research university in Munich with strong focus in science and engineering
No interview	
Services Offered	**Additional Notes**
• Strong research links with life sciences, including bioinformatics and biotechnology	• Research partnership with ETH Zurich • Founded in 1868 • Published multiple papers about additive manufacturing in otology, including creating ossicular prostheses • Their Institute of Microfabrication and Medical Devices has created a functional model of the middle ear using additive manufacturing (using SLM-- Selective Laser Melting)
Tags: European; Metals; University	
References	
• Website: www.tum.de • Contact Email: info@tum.de • Paper: “A 3D-printed functioning anatomical human middle ear model” (Kuru et al, 2016)	