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MASTERARBEIT / MASTER'S THESIS

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Conceptualization, Potential, Imaginations, and Expectations of Additive Manufacturing in Austria:
Visions of Future Social Implications of 3D/4D Printing

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1 Introduction

Key Words : 3D printing, 4D Printing, Austria, Additive Manufacturing, Atlas.ti, Black-Box, Killer Application, Controversy, Description, Engineering Technology, Expectations, Experts, Future Making, Grounded Theory Method, Hackers, Mid-set Shifting, Regulation, Social Implications, Science, Technology, & Society, Script, Sociotechnical Imaginaries, Third Industrial Revolution, Inscription.

Abstract: Three-dimensional printing is slowly becoming less of a novel techno-scientific invention and more a part of mainstream consumption and public debate, such as in the case of the printing plan, which allows users to build products for numerous applications in everyday life. When talking about the material outcome of this technology, all things 3D printed have one thing in common: a rigid object. Many researchers are already thinking of future developments in the field: namely, 4D printing. Some scientists are developing a special type of material(s) that can change their behavior, reshape, or self-assemble over time. Today, the main body of literature on 4D printing covers the engineering aspects of this technology and less is said about its social characteristics. This master thesis investigates social characteristics and future social implications of additive manufacturing, as there is a gap in this dimension. The aim is to explore the imaginable future of 4D printing in terms of the social transformations that it may activate and to evaluate the costs and benefits of eventual mass exploitation of this technology in the future. This thesis focuses on the social role of 4D printing as well as the emerging opportunities and controversies which arise from its broader application, along with the roles of designers and users in shaping the social impacts of this technology. The project investigates how, in the Austrian context, the future of 4D printing is imagined for everyday life uses by the institutionalized engineers and non-institutional '"hackers"' shaping the design process of the technology. How are visions of future expectations of additive manufacturing imagined, created, and defined by designers of this technology in Austria? How do they see its potential in shaping society in the future? What social implications can we expect from 3D/4D printing in the future?

1 Introduction

Schlüsselwörter : 3D-Druck, 4D-Druck, Additive Manufacturing, Atlas.ti, Black-Box, De-schreibung , Drehbuch, Dritte industrielle Revolution , Experten, Erwartungen, Gesellschaft, Grounded Theory, Hackers, Kampf, Killer-Applikation, Mid-Set Shifting, Regulierung, Soziale Implikationen, Sozio-Technischen Vorstellungen Technologie, Ingenieurtechnik, Inschrift, Zukunft

Zusammenfassung :
Drei-dimensionale Druckmethoden wandeln sich langsam von neuartigen Erfindungen hin zum Mainstream, sowohl in ihrer Anwendung als auch in der öffentlichen Debatte, so etwa am Beispiel des "printing plan", welcher die Herstellung zahlreicher Produkte mit diversen Anwendungsmöglichkeiten ermöglicht. Eine Gemeinsamkeit dieser Technologien im 3d-Druck Bereich stellt die materielle Beschaffenheit der Endprodukte dar: ein festes Objekt. Viele Forscher denken bereits jetzt über zukünftige Entwicklungen in diesem Bereich nach: 4d-Druck. Einige Forscher entwickeln spezielle Materialien welche ihre Eigenschaften verändern können, ihre Form verändern oder sich eigenständig zusammenfügen. Heute beschreibt der Großteil der Literatur die technischen Aspekte dieser Entwicklungen und weniger die sozialen Eigenschaften. Diese Masterarbeit untersucht die sozialen Eigenschaften und die zukünftigen sozialen Implikationen von additiver Herstellung (additive manufacturing), da es in diesem Bereich noch lücken gibt. Die Verbreitung additiver Herstellungsmethoden bietet ein enormes potential für soziale Veränderungen und ermöglicht neue soziale Realitäten. Gemeinsam mit zahlreichen Anwendungsmöglichkeiten in der Medizin, Ingenieurswesen oder Unterhaltung werden neue Formen sozialer Kollaboration und Innovation, Räume sozialer Aktivität und sogar Konzepte von Herstellung und Unternehmertum geschaffen. Jedoch werden durch die neuen Anwendungsmöglichkeiten auch Herausforderungen für existierende Regelungen und Sicherheitsvorkehrungen geschaffen. Dieses Projekt soll die Vorstellungen von zukünftigen Entwicklungen von 4d-Druck in hinbetracht auf die soziale Transformation welche ausgelöst werden könnte untersuchen und bewertet die Kosten und Vorteile der massenhaften Anwendung dieser Technologie. Der Fokus liegt auf der sozialen Rolle von 3d/4d-Druck und umfasst die potentiellen und entstehenden Möglichkeiten und Kontroversen welche sich von der breiten Anwendung ableiten zusätzlich zu den Rollen welche Gestallter und Nutzer in der Ausformung der sozialen Effekte dieser Technologie spielen. Das Projekt untersucht wie, im Kontext Österreichs, die Zukunft von alltäglichen Anwendungen von 4d-Druck von herkömmlichen Ingenieuren und "nicht herkömmlichen" Hackern vorgestellt wird. Wie stellt man sich die Zukunft additiver Herstellung vor, wie werden diese von Anwendern kreirt und

definiert? Wie wird das Potential gesehen die Gesellschaft zu formen? Welche sozialen Implikationen können wir von 3d/4d-Druck erwarten?

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1 Introduction

3D Printing of Smart Materials "SM"[1], or 4D Printing[2], poses many challenges which I find interesting for Science, Technology, and Society Studies ("STS")[3]. It is unique in the sense that the shift from 3D to 4D introduces a new type of "non-human agent". Interestingly, 4D printing is not a respected term among many scientists across the world, as theterminology is perceived just as a marketing tool for the Massachusetts Institute of Technology (MIT[4]) and the MIT's way of getting attention from media, alongside possible advantages (Pei, 2014).

Scientists also hold different standpoints towards how this technology actually works, and many of experts in the field do not agree with the term used in connection with 4D printing, where the fourth dimension stands for time. They view the "programming" of materials as a way of implementing biological rules and biomimetic composites into additive manufacturing, therefore controlling the action by understanding these biological capacities. Another issue arises with the degree to which MIT controls the printed materials, as scientists cannot find consensus as to what level humans are controlling the printing[5].

The issues mentionedabove, misunderstandings, and disagreements between conceptualizers of 3D printing create a technological controversy, and stimulate discourse on many levels. According to Sismondo (2010), studying a technological controversy is a natural way to brighten and broaden scientific knowledge about artifacts. The fact that scientists call the same phenomenon by different names but at the same time call different phenomena (as 4D printing brings a huge variety of applications) by the same name has made me realize that a future is being created now, just by disagreement on terminologies. "*The future of science and technology is actively created in the present through contested claims and counterclaims over its potential*" (Brown, Rappert, and Webster, 2000, 130).

A new categorization is called upon for this non-human agent, and invites a deeper investigation into how scientists conceptualize it. This master's thesis wishes to investigate how, in the Austrian context 4D printing is defined and the future of 4D printing is imagined for everyday life uses by the engineers shaping the design process of the technology. The aim of my project is to investigate how designers of this technology imagine the future of 4D-printing in

[1] See Chapter 10.1.1, 3D Printing and 10.1.13, Smart Materials "SM"
[2] See Chapter 10.1.2, 4D Printing
[3] See Chapter 10.1.14, Science, Technology, and Society ("STS")
[4] See Chapter 10.1.9 Massachusetts Institute of Technology ("MIT")
[5] See Chapter 5.1.2.3, Inscribing Additive Manufacturing/Philosophy of Engineering Technology

terms of possible applications , social transformations and regulations. As an STS scholar, I see the need to explore possible future scenarios for Additive Manufacturing of Programmable Matter ("PM") [6]and Smart Materials "SM")[7].

Futures on their own, but also the future of technologies, have been one of the prominent foci for STS and the sociology of expectations (Borup, Brown, Konrad, and van Lente, 2006). The way in which promises and hopes interact with society also influences the social outcomes of a given setting. This can be also understood as "co-production" (Jasanoff, 2006) which is intertwined with "sociotechnical imaginaries" (Jasanoff , 2009), and their roles in how society influences the future of technologies on the basis of "hope" and "hype" (Brown, 2000).

Conceptualizers of technology play a dominant role in creating imaginaries but also in "in-scribing" (Akrich, 1992) their visions of the world in regards to the technology and its capacities, and by that they create a "script" or a "scenario". According to Akrich (1992) designers cannot be the only ones who fully control the "script" with their often technical and subjective points of view. Instead, "*…we have to go back and forth continually between the designer and the user, between the designer's projected user and the real user, between the world inscribed in the object and the world described by its displacement"* ((Akrich, 1992 ,208-209).).

Most current experiments are being kept secret by scientists and being kept as top-secret by the US army as the biggest investor in this field (Fitz-Gerald, 2013), but as an STS researcher I need to stress the need to also involve other stakeholders, scientists from different fields and, lastly but most importantly, also social scientists in the development of such a technology to create "informed prediction" (Verbeek, 2006).

It is obvious that experts and conceptualizers of technology are from a privileged part of society who also create a "'black-box**": "** *... the conversion of sociotechnical facts into facts pure and simple depends on the ability to turn technical objects into black boxes. In other words, as they become indispensable, objects also have to efface themselves*" (Akrich, 1992, 221).

In many old sci-fi books, a machine was often discussed: a device able to create anything one could think of. We can simply understand this as a device able to construct anything from food to the newest hi-tech technologies from "universal matter". For instance, in Star Trek, the authors of the novels and the comics needed to deal with many anticipations and issues: for example, how to imagine a working spaceship without the reader being distracted from the main storyline by asking questions of existence and doubting the possibility of such a spaceship. One of the obvious problems that would need to be solved was food. This was firstly addressed by authors in terms of having a "food synthesizer", which was a previous version of a replicator,

[6] See Chapter 10.1.13 Smart Materials "SM"

[7] See Chapter 10.1.12, Programmable Matter "PM" and 10.1.13, Smart Materials "SM"

and it was able to create only food. However, a newer version of a "food synthesizer" became a replicator: "*The so-called 'replicators' can reconstitute matter and produce everything that is needed out of pure energy, no matter whether food, medicaments, or spare parts are required*" (Schüller, 2005, 15).

We can see many similarities when we compare 4D printing or 3D printing of programmable matter and smart materials to the "replicator". To start with, according to many scientists, authors, and NASA, 3D printing of food in space will solve the issue of sustainability of humans in space. So, in fact, we are not that far from having the first version of a "replicator". It is interesting to see the same chronology of implementation and reasoning regarding this issue in reality compared to sci-fi from the 1960s. If we develop the comparison even to a greater depth, we can see more similarities but also many differences. One of the most important differences is even if the "replicator" was producing objects from "nothing", for 3D/4D printing there needs to be existing matter for the production to take place. What is more interesting and fascinating, but also a disturbing difference, is the fact that scientists have already created a new class of disruptive technologies by implementing smart materials and programmable matter with 4D printing that is exploring 3D printing in a completely new dimension (Campbell, 2015).

My interest is to give an STS evaluation of the technology of 4D printing. It is unique in the sense that the shift from 3D to 4D introduces a new type of non-human agent, which can change its shape and behavior over time like a robot or computer, but without humanly pre-coded microprocessors, circuit boards, wires, or motors.

Skylar Tibbits (2013), an MIT scientist whose research focuses on developing self-assembly technologies, stated that: "*We make machines that make things; we're integrated into that theme. We're arguing that people can collaborate with materials and materials can be collaborative. It's not just us making stuff and forcing materials into place, it's materials making themselves.*" (Tibbits, 2014, Interview with Paul Wallbank, Personall Interview, Sydney , April , 30 , 2014).

A new categorization is called upon for this non-human agent and calls for a deeper investigation into how scientists conceptualize it and what scripts (Akrich, 1992) they are considering adopting. On the other hand, it is crucial to research the group of "hackers" as they will most probably be the first group who will be able to "hack" the script and "de-script" the technology.

One of the main advantages is the fact that for 4D printing, the "black-box" is not yet closed, and this allows a possible realistic contribution from this master's thesis.

I think the best way to conduct the research and gain information about the current development and possible future trajectories of this technology is to interview the most prominent and influential experts in Austria in the field of additive manufacturing. On the other hand, the view of the scientists who are considered institutionalized professionals would give us only the opinions from one side of the coin, and I see the necessity to compare and contrast the expert interviews to opinions and standpoints towards 4D printing as a novel technology with a social group called "hackers" who represent a free laboratory in exploring technologies. "Hackers" have been working with 3D printers from its early start in 1980s. One of the arguments why "hackers" are relevant for investigating the future of any technology, andeven more so additive manufacturing, is that "hackers" are most likely to be the first group to open the "black box" and try to "de-script" the technology. The aim of this master's thesis is to investigate how the futures of 4D printing are imagined by designers of this technology in terms of possible applications, social transformations, and regulations.

In this project, the aim is to study the possible social implications of 4D printing or, as some scientists argue, 3D printing of smart materials and programmable matter. I find it crucial to research the technological future implications before the technology is fully developed and put into society.

Many scientists consider 3D-printing as the next possible industrial revolution (Berman, 2012). Nowadays, 3D printing, also known as a system of additive manufacturing, is certainly being increasingly utilized in many different industries. Although we do not find them yet in households, in a few years, because of decreasing prices, the situation may change. 3D printing is interesting also because of its more economic materials processing potential. This is mainly because of its difference from classical manufacturing (subtracting manufacturing), where the process of production left a significant amount of waste. 3D printing uses a system of additive manufacturing, where the printer only uses the exact amount of material that is needed to create a new product. This results in less expensive production costs (Yoder, 2013).

3D printers were firstly limited only to print plastics, but it did not take long for scientists to find how to add and print more materials and chemical elements. This has opened new amazing possibilities by creating new printed products, which nobody in the past would have ever dreamed of, ranging from metals and microprocessors to simple human body parts like ears or bones. The system of additive manufacturing seems to be accelerating more and more every day, and "although 3D printing is not familiar amongst ordinary people‘" (Tahiri, 2013), this manifestly revolutionary scientific invention has continued to advance. This at least seems to be the dominant storyline. For sure, the system of additive manufacturing brings many visions of beneficial applications for society, but on the other hand it also brings with it many questions about regulations and avoiding possible abuses. A famous example is Cody Wilson, a then 25-year-old student from Texas, who in the year 2013 was able to print a fully functional gun after exploring the possibilities of a 3D printer. Another issue which additive manufacturing brings with it is the enhancement of translation between the digital and physical world and by that also questions of copyright. Printers, which are able to build a three dimensional solid object from computer binary code are seen "*as devices that provide a solid bridge between cyberspace and the physical world*" (Barnatt, 2013 , 4). According to many authors, including Susson (2013), if it is possible to design something on the computer, it can also be printed and turned into an object. A good instance of this is the Aston Martin DB5, which was needed for the shooting of the James Bond film *Skyfall* (2012). Purchasing a real model of an Aston Martin DB5 would have cost a lot of money, even for such a huge Hollywood production. Instead of using the real thing, the movie used a 3D printed car, which was identical to the original. Obviously, being able to access digital plans and scripts for almost everything and make a 3D print immediately could bring a world close to anarchy, and copyright as we know it today will have no chance to protect intellectual property. A world where everyone is able to print anything because only one-tenth of the amount of material is needed to create the same product compared to subtractive manufacturing Susson (2013) could also possibly lead to overprinting or overusing the technology, which could lead to possible environmental problems. Olson (2013), when talking about the material outcomes of this technology, claims that all of 3D printing has one thing in common: a rigid object.

On the other hand, the development of nanotechnologies and implementing them with "smart materials" and "programmable matter" creates an absolutely new way of how design and additive manufacturing can work.. Arkenberg (2013) also proposed that printers also proposed that barriers between biology and technology will start to fall in the near future.

Developers from the Massachusetts Institute of Technology (MIT) have developed and introduced to the world a technology where 4D printing uses a 3D printer for new self-reconfiguring, programmable material. Their research demonstrates the possibilities for creating materials which are able to be reshaped and inscribed into various preprogrammed "end results". 4D printing is considered by many scientists to be the future of design and industrial production because of its efficiency (Tibbits, 2013). From a sociological point of view and from the point of view of Actor-Network Theory (Latour, 1987), this technology introduces a new type of "non-human" agent which can change its shape and behavior over time like a robot or computer, but without humanly pre-coded microprocessors, circuit boards, wires or motors. MIT-based Skylar Tibbits, whose research focuses on developing self-assembly technologies, stated that *"This is the first time when the program and transformation has been embedded directly into the materials themselves".* (This is the quote from the video" (Tibbits, 2013, Ted, 6m 14s). This new feature combines the world of nano-scale programmable, adaptable material, also called smart materials, programmable matter, and a built environment. Scientists are experimenting with objects that can be printed, self-constructed, and "self-assembled", which is instigated by an external stimulus, such as water, heat or movement. Smart materials and additive manufacturing in the form of 4D printing bring a new way of working with the materials. To bring a couple of very simplistic examples, imagine that you order furniture and instead of spending time on construction, the material would build itself. Another example of this technology could be the use of an army wearing uniforms which change color depending on the temperature. If we think about this on a large scale, 4D printing could mean a huge improvement in the future of how design and manufacturing works, especially in inhospitable places like space. We can imagine 4D printed creations in various applications and that is what is unique about this project. It deals with the discovery of a completely new way of how materials work.

This leads me to the point out that 4D printing is a very important topic. Considering the social transformation and the fact that the existing literature covers mainly only the engineering part of this emerging technology, there is a certain need to question its potential social characteristics and implications in the future (Ratto and Ree, 2012). The aim of my project is to investigate how institutional and non-institutional designers of this technology imagine the future of this technology in terms of its possible applications and social transformations. In my opinion, concepts used in this thesis can be beneficial for the investigation of the future for 4D printing in Austria and its role as a new type of non-human actor. It is crucial to study 4D printing through the lens of STS to be able to learn from the past and to look at the future by introducing a new way of thinking about what could possibly be the start of a new generation of technologies.

1.1.1 Description of Content

This master's thesis is structured as follows: Firstly, I am going to address the issue of additive manufacturing and smart materials, which is vital for understanding the problems of 4D printing. I will continue by relevant concepts from STS that seek to describe the socio-technical imaginaries (2.1) and socio-technical controversies (2.2). As for the novel technology, understanding the laws of development of the technology is essential. Therefore, I will follow up these controversies and continue with questioning how are actually technologies understood in contemporary society (2.3). Technologies are designed by researchers who insert so-called "script" (Akrich, 1992), which influences how a given technology will be used (2.4) What goals will technologies be fulfilling depends on politics, business and the various stakeholders (2.5). By this will be shadowed main STS concepts that will help clarify the issue of 3D/4D printing.

Furthermore, I am going to elaborate brightening of the process of research (3) by explaining the research methods that I have used (3.1). Between these methods I included expert interviews (3.1.1), focus groups (3.1.2) and finally the empirical analysis I conducted through the Grounded Theory Method (3.1.3) within a virtual environment program for qualitative data analysis (3.1.4). After describing the methods that I have used, I will describe the actors whom I studied and what influenced my direction to get to them. The main participants in the research were scientists (3.3.1.1) and hackers (3.3.1.2).

After outlining the methods and materials I am going to get to the research question (4) that could introduce some aspects on which I was focused when doing the research. Further, I am going to interpret the data (5), which will include analysis of the experts/scientists and hackers separately. Gradually I will describe the standpoints of scientists and then by using concepts from STS, I am going to analyze the attitudes of the experts (5.1). By using the results of the analysis of these attitudes, I will critically look at hackers and focus on their uniqueness, and on how their attitudes enhanced my prior knowledge, initially gained in the chapter dealing with the experts (5.2). I am going to end this chapter by recalling the contribution of the actors that I examined (5.3).

In the next chapter (6) I am going to link the attitudes of all stakeholders in orderto exhaustively describe the interestsof all playersas a whole. This section, although it draws on STS concepts, is written with the goal of being as clear as possible for users of the technology of 3 D/ 4D printing.

In order for the reader to be able to evaluate the accuracy of my analysis, I have offered a chapter describing the progress of data elaboration (7). The main aspects of the development of this technology, which I have clearly demonstrated, will be presented in the conclusions (8). The list of literature usedin this master thesis can be found in the bibliography (9). At the end of the work are attachments to which I will refer during the work in terms of terminological explanation and clarification (10). The master thesis is finished by additional methodological subsections (10.2, 10.3) and a detailed description of both hacker groups (10.4, 10.5).

1.2 Additive Manufacturing: From 3D to 4D

"*Introducing programmable capabilities into 3D-printed materials could enable robot-like capabilities embedded directly into the materials, without the need for energy-intensive and failure prone electro mechanical devices. Such capabilities could be greatly beneficial to society, but also open the potential for new risks*." (Campbell, Tibbits 2015 , 3).

When "printing" multiple Smart Materials "SM"[8] and Programmable Matter "PM"[9] by combining them in one "printed" product, scientists at MIT are comparing these combinations with reference to DNA-driven biological systems.

Lipson and Kurman (2013 , 7) explain*: "Biological life is composed of twenty two building blocks amino acids that arrange themselves in different permutations to give rise to a myriad of proteins and eventually life forms…"* Biological life forms are able to self-repair and reuse biomaterial, as all biological life is made of just twenty-two building blocks. Coming back to the "replicator" which was suppose to appear in 24th century, it seems that current 3D printing is very close to this, as it is able to combine materials. However, by combining SM and PM,it seems that 4D printing will exceed the limitations of the "replicator", and we are only at the very beginning of 21st century. Another important work that envisions the futures of 3D printing is a book *Third Industrial Revolution* by Jeremy Rifkin. (2011). In this book, additive manufacturing is seen as having a certain impact on the democratization of manufacturing by accelerating innovation and reducing logistics costs as well as saving energy. However, the book was published in 2011, and since then, additive manufacturing has massively expanded and been implemented on a new set of industrial materials, like metals. Emerging advances in combining SM and PM have brought new challenges and which we need to research now in order to be able to face them in the future.

According to Chris Arkenberg (2013), who is a research and strategy lead at Orange Silicon Valley, we can expect that in the next decade, the barriers between biology and technology will be thinner and thinner, and might even fall completely. Arkenberg (2013) predicts that: Architecture will lose its formal rigidity and it will get closer to the life we see in plants. As 3D printing is already used by the military, and as the US army is the biggest investor in 4D printing (Fitz-Gerald, 2013), we can expect this technology to find numerous applications in the future, and for it to give rise to different kinds of social implications and social transformations. Hence I am stressing the importance of researching this technology in the greatest depth because it would not be the first time when society will face the so called "Frankenstein Complex" (Asimov, 1978). Great instance of how additive manufacturing could be turned against the user and the environment is the sci-fi novel called *Kiosk* (Sterling, 2007)

[8] See Chapter 10.1.11, Smart Materials "SM"
[9] See Chapter 10.1.10, Programmable Matter "PM"

which sketches a dystopian future of 3D printing in ''East Europia''. To cut a long story short, the author imagines 3D printing as a completely commercialized service, where humans are able to find printers on the streets with the same frequency as fast food takeaway outlets, and additive manufacturing gets to the point where it is so overused that it causes an environmental issue.

"[S]cience and technology studies have shown that it is hard, if not impossible, to predict with any accuracy the future consequences of new technologies for society and the environment" (Swierstra and Jesma, 2005, 203). This is why as an STS scholar I am going to focus more on understanding and eventually explaining possible future scenarios rather than predicting them.

One of the efforts to sketch the future of 3D printing technology is a book by Weinberg (2010), *It Will be Awesome if They Don't Screw it up*, which questions the expeditiously emerging technology and the relations of existing laws and regulations. It mainly focuses on the issues of intellectual property rights. 4D printing and its numerous applications and speed of development is seen as magical in many different industries. However, policymakers needs to work on the understanding of the capacities of 4D printing and also get ahead of its curve because while the technology offers enormous possibilities and potential achievements, at the same time, it is associated with both expected and unexpected dangers.

1.3 Smart Materials/Programmable Matter

*"There's Plenty of Room at the Bottom"*is how physicist and later Nobel laureate Richard Feynman started a dynamic development of nanotechnologies lecture in 1959, at the beginning of an era that has brought into our lives a truly revolutionary change. The rise of industries after the second World War and collaboration between different sectors of technology, which included mainly design and engineering in car manufacturing, had brought about thedevelopment of synthetic materials (Tovey, 1997). With the development of nano-materials and the rising popularity of nanotechnologies being implemented in various businesses and manufacturing processes, scientists started incorporating physics to design. With this new set of experiments they defined smart materials and programmable matter (Cross, 2001). Smart materials started to emerge in 1990s. Even if they seem very promising for the future with the invention of 4D printing, which can essentially be seen as the printing of smart materials, it is important to question the future social implications attached to these technological advances. It is also essential to realize that smart materials will enhance the possibilities of how the materials can perform because they will create new ways for how the material will interact with the user (Lefebvre, Piselli, Faucheu, Delafosse and Del Curto , 2014).

As a social scientist or STS scholar I see this as a fascinating start of the new era mainly because not only can a new-non-human agent be created, but also this new non-human can be massively reproduced, used, and abused in different ways for various aims. This obviously raises a lot of questions about the future of 4D printing or 3D printing and smart materials. According to Lefebvre, Piselli, Faucheu, Delafosse and Del Curto , (2014 , 368), in order to achieve an innovation there needs to be: "*a strong knowledge transfer between the technical artifacts produced by physicists, their use in product offers by designers and their implementation in industry by engineers."* I would disagree . A selection of experts, such as physicists, designers, and engineers, has already been collaborating on scientific issues. Their contributions are necessaryfor any upcoming technology, in our case, for 4D printing. In my opinion, now is the right time for the social scientist to join and look at the future of this technology from a different angle. Passaro (2010) has already been thinking about smart materials as an artifact which is able to affect the user's senses and emotions. Toffoli and Margolus (1991) imagined something currently being called "programmable matter". It is based on the idea that, due to current knowledge in the fields of nanotechnology and quantum mechanics, people will have a possibility in the near future to be able to change the properties of matter at the atomic level. This change will lead to the matter behaving as needed and desired at any given time. McCarthy (2003) extends the concept of software from being a simple program to work on computers to a virtual world that has the power to directly manipulate matter.

Programmable matter presents a new technological revolution, which, he stresses, will change our lives more than anything else in the past. I find this extremely fascinating and disturbing at the same time. This technology develops extremely fast, and even in its early stages already seems to prove this interesting hypothesis. As it is capable of influencing the user in a new kind of a way, to what extent will this technology be able to alter the users' senses and emotions in the future? What capacities it will have? Even more disturbing is that smart materials are already demonstrating that they can also express unusual behavior and surpass the trajectories of what the designer put into them. If we take into account that this technology might be massively producible and reachable to practically anyone who can buy a 4D printer, it is crucial to question this technology and its future applications. Smart materials and programmable matter are based on the input-output principle, which is very important for commanding such technologies.

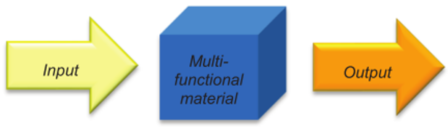

Figure 1.1: Explains the functioning of Smart materials : https://hal.archives-ouvertes.fr/file/index/docid/995958/filename/STS2014-LefebvreEsther-SmartMaterials-DevelopmentOfNewSensoryExperiencesThroughStimuliResponsiveMaterials.pdf

1 Introduction

On the basis of the input-output principle, Addington and Schodek (2005) introduced five basic characteristics for smart materials and programmable matter to describe how these materials are able to "behave". The first characteristic is "Immediacy", which is defined as an immediate response and reaction in real time to external stimulus. "Transiency" refers to reacting to multiple environmental states, and various environments influencing the properties of smart materials. "Self-actuation" is characterized by being controlled by internal "programming" or "intelligence" rather than external stimuli. "Directness" represents an immediate response. The output is generated automatically and straight away after the input is given. "Selectivity" is the final characteristic, and it refers to the predicting of output and a direct "*approach to maintaining environments"* (ibid., 209).

I find the definition of input/output very interesting because it is a perfect explanation of what designers are going to put in and they will also expect to gainas an end result. This presents another argument for why scientists/designers/experts are the most relevant to conduct research with in seeking answers to the research question. They have always been the ones who told us what can we expect in the future. This technology brings for social scientists many questions about the future, and one of them is whether or not new materials will also bring new interactions with users. This idea is sketched already by Passaro (2013), who realized that the new reactive nature of smart materials/programmable matter will foster the interaction between smart products and users. In my opinion, it is of great importance to research how smart materials create new interactions between products and users and what we can expect from it in the future. If we look at this new set of technologies through "Actor Network Theory" (Callon, 1986; Johnson, 1988; Latour, 1987), it is obvious that a completely new type of non-human actor is introduced. It is alarming that even in the early stages of research smart materials and programmable matter already show unusual behavior (Esther, 2015). The input-output principle does not always work as predicted. If this is the case in early stages of this technology, what can we expect from it in the future when the technology will have more capacities? We need to make sure scientists are aware of all the possible obstacles and that the "black-box" is going to be closed once the designers' inscription reaches the stage that most of the possible violations are going to be avoided. I would love to say 'all the violations', but I am a realist. I know users will always find a way to "descript" (Akrich, 1992). According to Addington and Schodek (2005), the range of applications for smart materials/programmable matter is very broad, and: "*[t]hese applications can be either extremely technical or directly used to interact in a spontaneous way with the end users.*"(Ibid.,379)

What can we expect from this technology in the future? Killer robot T-1000 from the movie *Terminator* is perhaps the most dramatic example of an object from the field of programmable materials that will one day be capable of pushing the button to change the shape, the color and the form of the object. T-1000 reminds me of a quivering mass of mercury that can change its shape and slip through each obstacle, and its hands and feet can turn into deadly weapons. Then, suddenly, it can take its original shape and continue its murderous rampage. It looks like the T-1000 cannot be stopped; it is a perfect killing machine. However, all of this is science fiction, but, as we know from STS, sci-fi often predicts the future (Kirby, 2010).

Figure 1.2: Demonstrates the possibility of printing smart material on an example official called: "Robotic Finger". We can see: a) a computer-aided design/visualization, b) a printed prototype, and c) the "finger" activated by a sliding joint https://www.researchgate.net/publication/262818283_The_Next_Wave_4D_Printing_ _Programming_the_Material_World

2 State of the Art/Theoretical Framework and Sensitizing Concepts

2.1 Socio-Technical Imaginaries

According to Skylar Tibbits (2013), prototypes of 4D printing are very simple, but the expectations and visions for this technology are magnificent. Science, technology, and society scholars are looking at these expectations to provide insights into the way how various technologies develop or fail. Many questions exist, and there are queries about the dynamics of expectations and whether it might be possible via the right kinds of expectations to predict mistakes that could be avoided (Brown, Rip, van Lente, 2003).

In other words, in science and technology studies, expectations are crucial for understanding the dynamics of innovation, and science always comes with certain expectations and visions of the future. The future is always visualized with certain expectations of science and technology. This can be also understood as co-production (Jasanoff, 2004).

As we have seen in the examples given above, it seems clear that the scientists who conceptualize and design 4D printing technology are working constantly with their visions and expectations, which are incorporated in the process of the creation of this new technology. "*Visions drive technical and scientific activity, warranting the production of measurements, calculations, material tests, pilot projects and models.*" (Borup et al., 2006 , 286) Therefore it is crucial to look at when, where, and for what purposes the scientists and the conceptualizers of this new technology do create such expectations.

Imagination is an important capability of humans. It helps give a sense of experience and the lessons needed for understanding. Thanks to the imagination of the world, scientists can imagine technologies that help with the creation process, and people can anticipate these technologies, which helps them be ready before the technologies are available on the market. In times of rapid progression of technologies, we need to be flexible and creative. We must make full use of our imagination and our ability to innovate.

The first of the questions which needs to be addressed from the beginning is this: why is it important to study future-making in general, and the future-making of 4D printing in particular in this project? Contemporary society is intertwined with the phenomenon of scientific/technological innovation and socio-economic growth, and "*[i]t makes a difference to our action potential whether the future is conceived as pre-given and actual, as empty possibility, or as process realm of latent futures in the making*" (Adam and Groves, 2007 , 164). Therefore it is important to look at how designers of 4D printing conceptualize the future of this technology by considering the social transformation. Another crucial question addresses how the descriptions of these conditions are created, and under which conditions the application of such a model is imagined. "*Who owns the future [...], has knock–on effects for the way it is perceived, the nature of the knowing and anchoring of responsibility.*"(ibid., p. 9).

Scientists, engineers, and designers of future imaginaries of 3D/4D printing, particularly in our case, also play a part in how scientists justify and position themselves. On many occasions, future visions are also organizational visions, to the extent that scientists can use these visions as a tool. This raises the ethical and political issue about future-making, and, therefore, it is important to look at who owns, produces, and controls the visions and imaginations regarding the future in 3D/4D printing in Austria. "*Political decisions that have the capacity to create major consequences that will affect countless future generations who are without voice or vote.*" (ibid., p. 200)

As my project aims to untangle the imaginations of the future in a specific country which is Austria, we need to understand the term "sociotechnical imaginaries", which was developed by Jasanoff (2009) and refers to "*collectively imagined ways of social life and social order reflected in the design and fulfillment of nation-specific scientific and/or technological projects*" (Jasanoff, 2009, p. 120).

As shown in the instance of nuclear politics in France, as discussed by Hecht (1998), the future of national identity is always related to the imagination of technological development. This leads me to the point that socio-technical imaginaries and techno-political identity are heavily intertwined with national and cultural mentality and heritage. Popular culture (Storey, 1994), which is mostly influenced by mass medias that represent "how the world is" (Jasanoff, 2004), creates what can be called a techno-political culture which can be described as: "*[t]he ways in which technosciences are interwoven with a specific society and how that in turn frames the way citizens build their individual and collective positions towards them*" (Felt, Fochler, and Winkler, 2010 , 2).

By comparing different social and political actors, for example experts and hackers, we can directly zoom in and see what the public expectations, imaginations, and hopes of the technology in the future are, and in so doing describe what the STI (Sociotechnical Imaginaries)[10] in Austria are about 4D printing. This method is also beneficial when comparing different political regimes, which is not our case. Nevertheless, in the conclusion I will sketch one main difference between representing 4D printing in the US and in the Austrian context. In general, comparing and contrasting differences has been a powerful tool for recognizing STIs. Jasanoff (2008) sketches four general problems we need to deal when characterizing a STI: Policy, Time, Space, and the last concept[11] of STI, which will help to explain collective and individual identities.

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[10] See Chapter 10.1.15, Sociotechnical Imaginaries

[11] "relationship between collective formations and individual identity" (Jasanoff, 2002, p. 33)

2 State of the Art/Theoretical Framework and Sensitizing Concepts

In many disciplines, not only STS, looking to the past and present is always beneficial when trying to figure out the future, because the present is what connects the past and the future. As Melucci (1996 , 12) explains, "*the future is born of the past, it is equally true that the past is also continuously shaped present by the future*''. This is why, in my opinion, we can look at the future of 4D printing through the lenses of previous sociotechnical imaginaries in a particular country. Previous national standpoints towards new technologies are always beneficial when looking at something as controversial as 4D printing because it helps us predict the level of national skepticism. It predicts how the country will react to this technology and it helps us also learn more about sociotechnical imaginaries in general. STS has been one of the prominent sciences to point out how imaginaries, expectations, and future-making are related to the notions of past and future, and how we can work with technologies from a time perspective.

Benedict Anderson in his famous work "Imagined Communities" (1983) developed an understanding of how can we look at a nation through different lenses. "Nation", in Anderson's (1983) terminology means "*an imagined political community and imagined as both inherently limited and sovereign"* (Anderson, 1983 , 49). We can understand this explanation as the fact that national decisions about technologies are not yanked out of thin air, but rather are heavily influenced by culture, history, and the psychological aspects of the nation in question. Jasanoff (2008) develops Anderson's (1983) notion of a nation by pointing out the importance of understanding the collective through shared practices of narrating, recollecting, and forgetting. Simplyput, these attributes play an important role when political standpoints towards new technological developments are being assumed, and they are not a singular but rather collective practice. It is more than obvious how important the past is when imagining the future. This phenomenon is explained and defined by Brown and Michael (2003), who define it as "people's memories of the future" (Ibid., 3). They determine a bifold concept of "*retrospecting prospects*" and "*prospecting retrospects*" (ibid., 3), which is how"people's memories of the future" are being employed to compose fluid, navigable, and substantial futures. "*Retrospecting prospects*"(Ibid., 3) can be simply explained as "*how the future was once represented*" on the basis of "*past futures*". "*Prospecting retrospects*" (Ibid., 3) means how prospects are being implemented in the present to create the future.

Sociotechnical Imaginaries[12] can be simply understood as how history is actively shaping and deconstructing attitudes of a particular nation through "past futures". Citizens establish individual and/or collective readings of "past futures". This creates their perceptions and - anticipations of "present futures" (Ibid., 6). However, this is a novel technology whose existence is not spread throughout the public. The best way to understand (and possibly predict) the

[12] See Chapter 10.1.13 , Sociotechnical Imaginaries

attitudes of the public is to engage the scientists who are in touch with additive manufacturing and hackers, as they play a role in the development they are closest comparing to the lay public yet still aware of upcoming technologies. Before creating the methodology, I did a little research myself. I confirmed my hypotheses about lay people and their understanding of 4D printing: 10 out of 10 people asked on the street did not have a clue what 4D printing actually stands for, and it was very difficult, and in some cases even impossible, to explain it to them. What is more, they thought that I was making fun of them. This might be why most research and analyses have focused on experts and hackers, and I will dedicate more time for this in the methodology chapter. It is important to point out little bit of terminology and elaborate on "technoscientific imaginaries" (Marcus, 1995), by which I mean to focus on "*the imaginaries of scientists tied more closely to their current positionings, practices, and ambiguous locations in which the varied kinds of science they do are possible at all*" (Marcus, 1995, 4). However, I want to understand and possibly explain rather than predict the public "sociotechnical imaginaries" as closely as possible. I will focus on more complicated phenomenon, as STS is about understanding and possibly explaining, rather than predicting.

As Taylor (2002) puts it: "*our social imaginary at any given time is complex. It incorporates a sense of the normal expectations that we have of one another, the kind of common understanding which enables us to carry out the collective practices that make up our social life.*" (Ibid, 106)

Jasanoff (2008) develops the argument for why 'sociotechnical' is the right word for creating this terminology. She also explains the importance of 'sociotechnical' in a society as being something similar to a sponge which receives and adopts science and technology on the bases of various *"imaginative work " (Ibid, 14) ,* of achievements *.* On the basis of the imagined achievements, visions and anticipations about collective good are created.

Sociotechnical imaginaries can be also seen as instruments of co-production**.** "*Co-production, at its core, is "the proposition that the ways in which we know and represent the world (both nature and society) are inseparable from the ways in which we choose to live in it."*." (Jasanoff, 2004 , 2).

With the idea of co-production, it is possible to design frameworks through the analysis of social science practices and furthermore to explain individual practices by focusing on scientific backgrounds and social conditions. It is crucial to understand the concept of "co-production" in the context of science and society. Co-production in this sense is the co-evolution, co-dependency, and co-production of science and society. The understanding of this should be on an excellent level if we want to study science, technology, and society because it refuses both technological and social determinism. Science takes place in society and it is tightly linked to technology and power. This may not be immediately visible as power is always about hiding the operation, separation of concerns and relevancies. Jasanoff's theory (2006) also leads to criteria which would presumably be associated with the idea of theories in physics such as "prediction". One key aspect of Jasanoff's (2006) theoretical focus is answeeing thw following question: "Does the theory predict correctly or not?"

Anyway, sociotechnical imaginaries can be understood as instruments of co-production. It is crucial to understand that STI is a way of predicting national choices, which are constantly in production. As Felt (2013) explains it "... *choices are not for or against technology, but for or against particularly imagined and inflected technologies--and these choices are never fixed, but a continuously in construction*" (2013, 17). Also, Brown, Rappert, and Webster (2000) argue that the future of science and technology and its creation are very active processes which are being composed via "*contested claims and counterclaims over its potential*"(Brown, Rappert, and Webster, 2000 , 3-20). This leads me to the point that the language of scientists, politicians, stakeholders, and collective actors play a crucial role when establishing or creating an STI.

2.2 Technological Controversies

Calling a thing by different terminologies or different things by the same term can also be seen as "technological controversy", which needs a subchapter of its own. Understanding the whole issue of 4D printing hinges on a shared, mutually understood vocabulary. Language is a part of future-making, and it simply starts by calling things differently from how they were called before.

In general, when a disagreement about certain technology begins to rear its head in the circles of experts, politicians, or scientists, we can say that we bumped into a technological controversy. In our case of 4D printing, we can talk about more points bringing up awareness that some of the opinions of social and political factors vary. Firstly, disagreements raise the language issue. As demonstrated in the analyses and conclusion, conceptualizers of 4D printing simply cannot agree on some terminologies and expectations, and many explanations about the technology still remain very abstract. The name itself, 4D printing, seems more a marketing strategy rather than a realistic invention for some people. According to Sismondo (2011), studying a technological controversy is a natural way to brighten and broaden scientific knowledge about artifacts. Obviously, other questions are about how the technology should be developed and what stages it should undergo in a legal process to be practiced in the right way. One of the key motives for this project is the fact that 4D printing is thus far not yet "’black boxed", and this makes it ideal for the research. Sismondo (2011) explains the term "*black box*" as an input-output device that is predictable, and once it is known how the technology is going to work, the "black box" is closed. This is something Latour (1987) calls an "immutable mobile", controlled by scientists or whosoever has the control, with the closure of the box simply taken for granted. Unfortunately, what happens many times is that the problems with the technology occur only after this process has taken place. Because 4D printing is in its early stages, the "black box" is not closed yet and since there already exists a discourse exists about this novel technology, the setting is ideal for research and further questioning. "*Once a fact or artifact has become black-boxed, it acquires an air of inevitability. It looks as though it is the best or only possible solution to its set of problems*"(Sismondo, 2011, 11)

Before the shaping of the technology is finished and the "black box" is closed, it is important to understand as much as possible about how the technical, political, social and economical actors are being active in influencing the process. In the chapter of research questions, I am going to get more in depth about what sub-questions have been asked in the interviews. Generally, these questions incorporate predictions of where controversy can be expected in the future of 4D printing. They mainly deal with how the technology should be used to bring about positive outcomes with its social implications, what features and characteristics it will have, as well as who should be responsible for the design, implementation, and closing of the "black box". The idea is to avoid mistakes from the past and to create the best possible technology of tomorrow, both for the user as well as the environment.

The "classification-continuum" of controversies by Nelkin (1995) shows how we can recognize the increasing participation of the public in controversies regarding the issues touched upon. Nelkin starts with "local" scientific controversy with little public interest and carries on with controversies over methods and resources used in science, controversies between scientific models and "alternative explanations". The essay ends with a description of controversies over certain techno-scientific applications with the highest public interest and participation. In my research on 4D printing, I am going to cover the last three types of controversies with the highest potential public interest, and that is why I consider this work innovative and beneficial.

Several typologies of disputes exist (Nelkin, 1985). Firstly, a dominant role in controversies is how people look at the world, and controversies arise mainly because of differences in the moral and religious implications of a certain technology. Secondly, we can talk about the obvious and everyday fight between political and economic aims and what is right for the environment. This leads me to Nelkin's (1985) third dispute, the stance of industrial and commercial practices and their impacts on health. The last dispute is the pressure between achieving individual goals and expectations, a corporation's expectations and the values of a community. An important thing to mention is that 4D printing is being touched by all these above-mentioned kinds of controversies.

STS scholars are used to dealing with controversies and have developed different approaches for how to analyze them. According to Brian Martin and Evelleen Richards (2001), the four most relevant approaches for this kind of study are positivist, group politics, constructivist and social structural. Firstly, the positivist approach is not convenient for this research as the positivist approach is built mainly on social scientists blindly accepting and not really questioning the scientists' opinions and attitudes about a technology.

I find the group politics approach convenient mainly because it is built on comparisons and contrasts of various social groups and their standpoints regarding upcoming technology. I partially do this in my research because I compare a group of experts with a group of hackers, but, at the same time, the opinions of experts vary to the extent that I cannot really lump them all together. Most relevant for studying 4D printing is the constructivist approach, also called sociology of scientific knowledge, which was developed in the 1970s. I find it relevant mainly because it focuses on science and technology that are still in the making (Brian and Richards, 1995).

Another characteristic of this approach is "symmetry" elaborated by David Bloor (1991) in "Strong Programme". The principle of symmetry lies in explaining the successful and unsuccessful affirmations of social scientists by the same explanatory resources. The crucial thing to mention is that, with the constructivist approach, "true" and "false" are being addressed strivctly in terms of scientific claims. The constructivist approach also shows that a major part of the dynamics of controversies is created by circumstances and factors like scientific reputation and funding.

In the case of 4D printing, I will be dealing mainly with so called cognitive and social controversy (Engelhardt and Caplan, 1987) because the main disputes in the field thus far have addressed little but knowledge and the classification what 4D printing actually is, its terminology and expectations for what its capacities will be. However, I also will be examining many disagreements about its social implications and non-scientific issues. I have found controversies in three major aspects: in language dealing with naming of the technology, in opinions about the regulation of the technology with which the black-box(ing) of the technology is closely intertwined, as well as in the "inscription" and "de-scription " (Akrich , 1992) of the technology.

2.3 Technology as Artifact

In our world, society has always been differentiated, and the standpoints of people towards technology have been separated. On one hand, critics of technology and technological civilization exist, and on the other hand, there exists a smaller group of philosophizing scientists and engineers who consider technology as the highest hope for humanity. In the most sophisticated form, we find a similar division in Carl Mitcham's (1994) work, where the author distinguishes between "Humanities Philosophy of Technology" and "Philosophy of Engineering

Technology". While the "humanities philosophy of technology" is more definable as criticism and sees technology as a dangerous aspect of human thought and action, "philosophy of engineering technology" understands technology as the model of all human thought and action.

Relationships between theory and practice, or between philosophy and technology, take different forms depending on how we understand what technology is. Mitcham (1994) shows a very detailed understanding of changes in the technologies themselves. In his work, he distinguishes and progressively elaborates on three main ways of understanding technology as an artifact. It is interesting to look at 4D printing through Mitcham's (1994) work, where the author describes three ways of using technology as an artifact:

a) Technology in terms of activities. This includes the processes of creation and the use of technology in itsconnection with other human activities. This opens up a very broad topic of the relationship between human activities and technological processes.

b) Technology as a type of will. An instance of this could be a description of control; technologies which serve someone's intentions as a symbol of political power or freedom, e.g. algorithms (Mitcham, 1994).

c) Technology as a type of knowledge. This view completely rejects the idea of technology as an object of philosophical reflection and emphasizes the specificity of the actual technological reflection of the world.

For one of the contemporary philosophers of technology, David Rothenberg (1995), technologies can be differentiated and classified according to the difference between transparent and transformational technologies. As the author explains it, transparent technologies are closer to human intentions and serve the aims of people, politicians, and institutions**,** while transformational technologies represent the emergence of a new aspect of our world, or new aspect of our existence in the world. Existence and technologies are, as Rothenberg (1995) explains, inseparable, and a transformational experience with one technology can be easily converted to a transparent one because the world is changing in relation to technologies. In this relationship, technologies are viewed as actually changing society. It is essential to understand that technologies which are considered "transformation technologies" can become "transparent" after some time.

To describe this change, Rothenberg (1995) introduces six categories through which he describes the transition phases from a transformational to a transparent form of technology. The combining of people and technologies, according the author, is a historical process through which it is possible to explain the different stages of the development of instruments. In the first category, Rothenberg discusses purely transparent tools. These tools only follow our intentions and needs without the requirement of being transformed or translated to "transparent". Another category belongs to tools that are easy to handle because the source of their movement and energy is not only human, but also comes from the outside world. As an example, we could use a sailing ship where the power source is an external mechanism, which is manipulated and regulated by humans.

The third type of technology works directly with energy, with which it changes the world. These technologies do not only receive, sort, and distribute energy, but they also change the energy itself into something else. An example of such a technology is oil being transformed into electricity.

Even if 4D printing is in words of MIT officially ''pre-programmed'' in order to make an action ..we can argue that, in reality, 4D printing only uses physical and biological properties that are very well calculated. In this manner, we could assign 4D printing to technologies that transfer energy from one state to a different one by being manipulated by a human.

Rothenberg (1995) explains and carries on with another three phases that are genuinely "transformational". They are tools that not only change and shape the world, but also human abilities, intentions, and needs. Through the process of transformation and the transition of "transformation technologies" to "transparent technologies", we have to realize that technology can simply represent different forms of relationships through which people engage with the world.

2.4 The Concept of Script/De-Scription of Technical Objects

"Prescription and Description of Technological Objects", "User Centered Design", and their social applications have been studied by many scientists, as well as technological and societal scholars who have been investigating the normative features built into the design of technology for the future "end user".

As is often customary to STS scholarly analysis, my goal with this thesis will be to extract the political, societal, and economical consequences in order to look at the hidden implications built into the technology of 4D printing, as well as to inspect the future political inscriptions the technology receives from its designers*. "A large part of the work of innovators is that of "inscribing" this vision of (or prediction about) the world in the technical content of the new object. I will call the end product of this work a "script" or a "scenario.""* (Akrich, 1992 , 208) It is certain that developers of 4D printing are constantly working with the imagination of users and potential future applications of this technology that are, to a certain extent, also the steering wheel of the creation process. I find it crucial to investigate the development of this novel technology by questioning the conceptualizers and their standpoints regarding the future social implications of 4D printing. It seems to be the best trajectory in order to untangle my research question (as stated below in Chapter 4). "*One way of approaching the problem is to follow the* *negotiations between the innovator and potential users and to study the way in which the results of such negotiations are translated into technological form*." (Akrich, 1992 , 208)

Akrich (1992) introduces the idea of the projected user, created by the conceptualizers of technology. The projected users are defined by particular motives, aspirations, and political biases. The designers, by these assumptions, inscribe this vision or script about the world and about the users into the technical content of the object. Scientists attempting to prescribe or predetermine the settings of a technological object ask the users are to imagine a particular piece of technology. The prediction about the user is scripted into or built in the technology. Technologies may become adapted to certain groups of users because of the implementation of specific ideas for future uses (Oudshoorn, Rommes, and Stienstra, 2004 , 31,).

A large part of the work of innovators is that of "inscribing" this vision of (or prediction about) the world in the technical content of the new object (Akrich, 1992). The description of technological objects (Akrich, 1992) can be simply understood as when a technological user uses or interprets a technology differently from the original idea of what 'the author intended'. As 4D printing offers numerous applications, it also brings along with it the same amount of possible violations.

Another useful STS idea on which we can build this concept is "I-methodology" (Akrich, 1995; Rommes, 2002). Conceptualizers and designers of new technologies predict and incorporate their own experiences, anticipations, and often even their own personality and mental models in the end product for the future users. The end result of the technology is expected to be impersonal and neutral, but frequently designers of technology create problems for the end-user, resulting from he or she not being connected with the designer's anticipations. This also brings up a question about the subjectivity and objectivity of designers when conceptualizing technology.

In Garrety and Badham's (2004) work, it is argued that user centered design (UCD) methods are tools for engendering new forms of socio-technical relations and, as the authors put it "*(UCD)—a set of principles and practices that aim to privilege the needs and aspirations of users in technology design and implementation*". (Ibid , 2)

One of the main points of interest about this sensitive concept is understanding the importance of taking users into account when designing new technologies because the identification of future users plays a dominant part in the process of creating and conceptualizing technology. This imaginary of future end-users is incorporated into the design and limitation of a given technology in order to create more a 'humane' technology (Garrety and Badham, 2004).

Many writers have noted that UCD projects often fail to fulfill the humanistic promises that are made on their behalf. This is interesting when looking at 4D printing as a technology that brings new "non-human" actor by trying to humanize different types of material while at the same time amazing imaginations and expectations of various future applications of4D printing are being created. Similar to what Steve Woolgar (1991) writes, the development of a particular technology brings up a relationship between the user and the device. In his work, the author demonstrates how the design and production of a new technology implies a process of configuring its user. This act of configuration involves defining the identity of users and setting restrictions upon their future actions through the functional design of the physical artifact with a focus on how it can be used (Woolgar, 1991).

It is important to look at this technology and understand that Akrich (1992) is right when talking about the designers and conceptualizers as the ones who try to control the script. However, most of the attention is concentrated mainly around designers and conceptualizers, and only a little bit is focused on the artifact itself with a "framework of action", as Akrich (1992 , calls it. "*Thus like a film script, technical objects define a framework of action together with the actors and the space in which they are supposed to act'*." (Ibid., 209). Latour (1992) comes to a rather different understanding of the idea of a script, and remains more concerned with the possibility of the artifact itself and its script as what controls "the program of action". (Ibid., 19) As he puts it, "*any artifact is only a portion of a program of action and of the fight necessary to win against many anti programs*". (Ibid., , 174) brings the idea that the "program of action" can be or is the inscribed conceptualizer of technology, but the artifact is mainly inscribed by "its very shape". This seems like a natural analysis from Latour, as he is also one of the most dominant representatives of the "principle of symmetry" (Latour, 1987). With this idea, Latour demonstrates that humans and non-humans should be studied symmetrically. Many authors agree with this way of looking at artifacts and propose that they are active in co-shaping the actor's action (Verbeek 2005; 2006). For me, Latour's understanding of script is a sort of natural idea that comes to one's mind when thinking about script and the fact that the artifact itself cannot and should not be underestimated, but rather needs to be considered as a master of its action.

As demonstrated by Latour (2000) through his most famous example of this phenomenon, the "Berlin Key", the script itself can control the action and be active simply by virtue of its existence. The artifact has its "program of action" and, in more ideal cases, also an "anti-program of action", as well as its "orders" and "prescriptions". Owing to the work of Akrich and Latour, we can diatinguish two basic types of scripts: the artifact's script and the designer's script. According to Akrich, designers are trying to incorporate certain scripts that will only allow uses that designers have approved and will disregard any undesired uses. I would compare this concept of script to riding a wild horse and trying to get him under control. Once the horse is settled, it behaves exactly as the rider wants it to behave. In reality, with different kinds of technologies the situation is much more complex. History yields numerous instances where designers' scripts have failed and were used or abused by users in various manners. Akrich suggests a "back and forth" method: a continuous design process of including not only designers and conceptualizers, but also everyone who is involved in the production process. "*[t]hus, if we are interested in technical objects and not in chimerae, we cannot be satisfied methodologically with the designer's or user's point of view alone. Instead we have to go back and forth continually between the designer and the user, between the designer's projected user and the real user, between the world inscribed in the object and the world described by its displacement*" (Akrich, 1992 , 208-209).

According to some authors, this process could be simplified by the utilization of "future scripts" (den Boer, Rip, and Speller, 2009). However, future scripts are very subjective and idealistic frameworks. *''Societies are not only held together by social relations and institutions, as sociologists and anthropologists claim, but by things as well* .''(Verbeek, 2005 , 125).

It is crucial to understand the term "technological mediation", which was firstly developed by Latour in "Where Are the Missing Masses? The Sociology of a few Mundane Artifacts" (1992) and "On Technical Mediation" (1994), and later by Peter-Paul Verbeek in "Artifacts and Attachment: A Post-Script Philosophy of Mediation" (2005) and "Materializing Morality: Design Ethics and Technological Mediation" (2006). "Technological Mediation" refers to a way of justifying how artifacts and people, or humans and non-humans, co-shape each other's actions. From the many examples, I find Verbeek's (2006) account of him riding a bicycle to university a very relevant one. He demonstrates that without him riding a bicycle, or without the bicycle being ridden by him, there is no such action as biking. "*Technological artifacts mediate how human beings are present in their world, and how their world is present to them.*" (ibid , 5)

Latour (1994) demonstrates four concepts of mediation: translation, composition, reversible black-boxing and delegation. To simply and briefly describe these four concepts: "*translation*" can be understood as the translation of a program of action, which refers to how the artifact can be used in multiple ways. For 4D printing, the various ways of translation can be seen already even in the early stages, and we can predict a huge growth in its translations.

"Composition" of mediation refers to a new program of action instigated by a "composite actant". Again, this is very relevant as new levels of "composition" in4D printing are being found every day by designers, and it is quite possible that users will look for new ways of acting when using this novel technology. This leads me to the third concept introduced by Latour, which is ''reversible black-boxing''. This can be understood as the moment when artifacts fail and the user or designer needs to go back and open the black-box to make it work again. Alternatively, it can also be understood as a form of de-script(ion) of the technology. The last concept of Latour's mediation is called "delegation", and it is also considered the "most important meaning of mediation" (Latour 1994,). For examining the concept of inscription of technological objects, it also seems the most relevant.

The example of a speed-bump is a good example with which authors offer to demonstrate the in-scripted program of action into material itself. Put simply, scripts mediate actions. It is also important to mention that prompts of delegation come from non-humans to humans and not the other way around (Verbeek, 2005*).* We can talk about "technological intentionality" and both the obvious and hidden intentions of artifacts. Again, I find this very useful and relevant for programmable matter, smart materials, and 4D printing in general. If the theory works with such efficiency with a simplistic example of a speed bump, what can we expect from materials which canbe programmed to create an action? It is crucial to question the designers regarding if and how such an inscription will be conducted.

In the situation we currently are in with regard to 4D printing as novel technology, it is obvious that conceptualizers of this technology are working with future visions and thereby relevant "anticipations", "inscriptions" (Akrich, 1992) and "mediations", more specifically "delegations" (Latour, 1994), and that they are incorporating these concepts in the process of development.

2.5 Normative Politics of Technology

The topic of the normative politics of technology has been touched upon by scholars like Winner (1980), Latour (1993), and Akrich (1992). They offer illustrations of the ways through which artifacts can contain political motives. Winner (1980) offers examples in which the design or the arrangement of a technology or system has set an issue in a particular community (e.g. Moses's bridges). Winner also talks about inherently political technologies or designs (e.g. tomato harvesting machines), which are human-made and are strongly intertwined with particular kinds of political relationships. With these examples, the author argues that it is important to acknowledge the idea of non-randomness in technological development, and to understand technological and scientific choices as developed by political norms. Science and technology modify the power of the state and other institutions in critical ways. The people producing scientific knowledge and technology often have motives which are not immediately made obvious.

On the other hand, in "Do Politics have ArtIfacts ?" (Joerges, 1999) the author argues that Winner's (1980) story is just a well-written paper without too realistic a meaning or the right explanation of the questionable inherently political quality Moses's bridges. The author pulls out many explanations for why the architecture of the bridges was never a racially or politically calculated plan. However, Joerges (1999) agrees with the main idea of Winner's (1980) text in that "power relations can literally be built into and perpetuated through stone" (Winner, 1986, p. 2). Joerges (1999) also addresses Latour's (1982) attitude towards Winner's (1980) text, and brings up the notion of "how to do things with words" vs. "how to do things with things", where Latour (1982) agrees with the possibility of moral and political implications of technologies. However, he points out that the power of artifacts is embodied solely in the relation and status of the technology in its network and in relation to other actors.

If the vision of the political nature of the technologies is developed even further, we can say that certain technologies not only encourage the establishment of specific social conditions (democracy or authoritarianism), but also have the power to promote and strengthen certain patterns of human behavior, communication, and according to Winner (1980), social order. If we take into account that 4D printing is not only a new technology, but a whole new way of how material will work, set to create numerous new inventions and uses for new smart materials, we can see the huge potential of this new technology to shape humans in the future for political purposes. The U.S Army is currently one of the biggest investors in the field of 4D printing (Fitz-Gerald, 2013), and we can imagine many ways in which 4D printed creatures could be used in various applications for political means. Many STS scholars ask the question whether establishing scientific or new technological phenomena constitutesthe process of "engineering ethics". This question is important, as it offers a way into examining what role morality plays in the work of conceptualizers. Swierstra and Jesma (2005) even bring up aninstance, where the Dutch Minister of Science brought to parliament the suggestion that Dutch scientists should also have an education in ethics to qualify for their work as engineers of ethics.

A very important feature of science is that many new scientific discoveries offer great promises for innovation but also possibilities of abuse and detriments to society. For an example of the "Frankenstein complex", we can citethe invention of dynamite, the discovery of radioactivity, the manufacturing of certain herbicides, and so on. If we consider that according to scientists who introduced 4D printing to the world, the most important innovative characteristic of the technology is that it seems to work on "its own", capable of being self-assembled to the desired shape and pre-programmed to the needs of its creator, then the moral roleof the designers of this technology should not be underestimated. As the main protagonist and man who invented 4D printing puts it, "[w]e make machines that make things; we're integrated into that theme. We're arguing that people can collaborate with materials and materials can be collaborative. It's not just us making stuff and forcing materials into place, it's materials making themselves" . ." (Tibbits, 2014, Interview with Paul Wallbank, Personall Interview, Sydney , April , 30 , 2014).

2 State of the Art/Theoretical Framework and Sensitizing Concepts

Engineering ethics play a crucial role in the possibilities of using new scientific inventions. However, it is obvious that in the division of science, decision-making and executive power come to a paradox once phenomena arediscovered, and those who invent the product are deprived of the power of directing the fate and effects of its invention. Politicians and sponsors become those who are '"steering and riding in the sail", so to speak. Commercialized science, technology, and sometimes even education become incompetent servants for the aims of politicians and corporations who love to deny any responsibility for the use of new scientific inventions of for their goals.

Nahuis and van Lente (2008) discuss the ways in which the relationship between scientific and technological innovation and democracy has been conceptualized to the present day. It is obvious that the same scientific invention can be used in different manners depending on of the goals and interests of the country where the invention is being used. For instance, in Austria, according to Univ. Prof. Emerson Lewko (2014), the potential of 4D printing lays mainly in its use in manufacturing and industrialization in inhospitable places. We cannot really accurately predict what the intentions are of the prominent investor of the US military in this field may bebut we can definitely assume that their aims are going to be about exercising power. Brown (2009) asks questions regarding how science becomes political in exercising power. He explains that technology is not simply created to be political, but it becomes so. We can ask the same question: how can 4D eventually become a political technology? We can also make use of the fact that this technology is still in its infancy to try to predict this "how". As we have seen, science can easily become political and scientific inventions can become "black-boxed" in a matter of seconds. Nevertheless, the whole process of how science becomes political in terms of exercising power is also deeply connected tohow scientists use laboratories...

In order to avoid the mistakes of the past where new generations of military technologies were adopted and utilized without really preparing or planning for the consequences, one has to be able to anticipate potential outcomes (International Red Cross, 2003).

3 Methods & Materials

In this chapter I will explain the methods and materials of my choice with argumentation for why I found these methods in particular to be the most favorable in answering my research question.

3.1 Methods

3.1.1 Expert Interviews

I have decided to investigate my research question[13] by conducting expert interviews with six Austria-based scientists whose primary field is additive manufacturing. All six scientists have different stakes and interests as regards additive manufacturing in Austria. An important thing to note are the individual motivations of these experts, which played a crucial role for me in choosing this method when preparing the research design. I also observed that the experts were very willing and curious to discuss 4D printing.

I chose expert interviews as a methodological approach deliberately, as I was expecting experienced, highly valuable information to be provided, mostly because of the high degree of motivation which seems to be natural to experts, and thus yields a promising method for gaining professional input. The ideal method would be a comparison of interviews between the experts and lay people, but as at this moment 4D printing technology is in its infancy, and lay people would not be able to answer all the questions, as they do not yet know that such a technology exists. This insight led me to understand that hackers are actually the closest replacement for lay people in this case, as they are not officially experts, yet remain demonstrably so invested in new technologies that they are able to provide answers to the questions at hand.

Are expert interviews really completely different from narrative-driven or focused interviews, and did I have to take a completely different standpoint compared to doing a interview with a lay person? The answer is 'yes', because methodological considerations are important where the definition of experts and expert-knowledge is concerned, and this has its own place in interview methodologies. An expert, according to Meuser and Nagel (1991), is someone responsible for the development of science, technology, or any kind of knowledge production. An expert is an active person who has access to first-hand information because he or she is either producing the information, scientific facts, or a part of the networks which produce the information. An expert or a member of the élite can be also someone who implements and controls policies and decision-making. It is important to differentiate between the two. According to Dexter (2006), an ‘’elite interview "*... is an interview with any interviewee [...]. who in terms of the current purposes of the interviewer is given special, non-standardized treatment.* "(Ibid., 18).

[13] How are different forms of "imagined futures" for 4D printing being conceptualized by the designers of this technology in Austria?

From a practical point of view, expert or elite interviews should take place in a setting where interaction or an argumentative/discursive way of interviewing plays an essential role in the production of valuable data. We can look at the understanding of the term "experts" from many different angles. For instance, in the sociology of knowledge, experts should be people who have special knowledge which is intertwined by their professions (Sprondel ,1979). It was obvious to me that in order to answer my research question, I needed to focus on conscious knowledge (Schütz, 1980), because implicit or tacit knowledge would not allow me to untangle my interests. We need to realize the simple but important fact that, in the mind, society is the body responsible for deciding who is an expert. n other words, experts are made by society, and society is mirrored in the people who stand as experts. Different approaches exist in how to answer the question of who qualifies as an expert. In the interest of efficient research it is crucial to interview the relevant experts in the field and therefore answer this question.

We can distinguish experts as "voluntaristic" and "constructivist" (Bogner, 2009: Littig, 2013). In our case, it makes sense to look for so-called "constructivist" experts: someone who has special knowledge and authority on a given subject. Geography also plays a role when it comes to the ways in which research takes place: the results of expert interviews could be slightly or completely different in different countries and with different experts. To me, Austria is a particularly interesting place to conduct expert interviews because of its national heritage. The higher the level of knowledge, experiences, actions, obligations, and processes of implementation to decision-making structures, the better the possibility of gaining data which, after analysis, will answer the research question.[14] On the other hand, many times prominence does not ensure the expertise; a phenomenon which Bogner (2005) calls the agent of truth.

Experts are usually motivated people who likely are willing to experience, cooperate, and exchange new information, and they usually work in networks and thus often one interview can easily lead to other interviews. The scientists whom I have been interviewing have high insight in terms of aggregated and/or specific knowledge. Three dimensions of expert knowledge exist. The first is technical, which relies on a specialization in the field and at the same time influences the field. This knowledge usually brings insights about details on operations, laws, and so on. Process knowledge is concentrated around routines and processes that are common, and the scientist is gaining expert knowledge because he or she is directly involved in these processes. Explanatory knowledge is built mainly around the subjectivity of opinions and beliefs.

Many STS authors, including Jasanoff (1995), Bogner (2005), and Torgersen (2005), have been pointing out the importance of using, implementing, and improving the interactions of

[14] *How are visions of future expectations of 4D printing imagined, created, and defined by designers of this technology?*

society and experts, as many inquiries into new technologies rely on the role of the "expert" in the center of the investigation.

Dorussen, Lenz, and Blavoukos (2005) argue that the selection of expert interviews as a methodological choice can be explained by and compared to the process of searching for directions on a journey. It is much more reliable to ask anauthority for advice; it is a promising strategy in gaining the right answer and not getting distracted by several different answers proposing different courses of action, which often simply leads to confusion and eventually asking the authority anyway. Bogner, Littig, and Menz (2009) suggest that picking an expert for an interview has, among many other benefits, also a strong likelihood for gaining more access and information from the field than a lay interview. The expert should be "the agent of truth" (Bogner, 2005), and, at the same time, his or her answers should demonstrate "the realist approach". According to many authors, using expert or élite interviews to gain this kind of information is also a prominent methodology in the social sciences. However, the paradox is that the literature elaborating on epistemological issues in this method is lacking. I think what makes an expert an expert is to, firstly, have "know-how", which we can understand as a sort of "left brain" quality: technical, processing, and logical. It is very important to also have so-called interpretative knowledge, or "know why" (Bogner and Menz, 2005)

In general, scientific expertise plays a crucial role when decision-making is being practiced. In STS, this has been studied and researched by many scholars, for instance Collins and Evans (2002) and Wynne (1989). In the case of eventual social conflict, an expert becomes someone who is a crucial force in influencing how the public anticipates future technologies. It is important to point out that neither sociology nor any particular methodology elaborates on the differentiation or the categorization of experts. We need to take into account that a variety of different experts and their hierarchies will create different levels of knowledge produced about different information. Many questions remain unanswered. Firstly, how should the interview be professionally prepared to enhance the potential of reaching a goal and answering the research questions qhile also fulfilling the purposes of an expert interview? Secondly, how should the data be analyzed, coded, and transformed into results?

Bogner (2005) sketches three basic types of expert interviews where each approach is used for a different goal:

- The explorative interview, which is supposed to navigate, investigate, and all in all work mostly for explorative purposes.
- The systematizing interview, which is concentrated and focused mainly on reconstructing expert's special "objective" knowledge in a particular field.
- The theory-generating interview, which also analyses the expert's special "objective" knowledge but is mainly reconstructing the implicit part of the knowledge of

action and interpretation. I found the theory-generating interview to be the most convenient for my research.

I think it is essential to question the realistic contribution, and also the reliability and validity of the gathered information. The "quality" of the outcome of a research project (Jochen, Gläser, and Grit Laudel, 2009) depends mostly on knowledge, the information produced, and above all the "quality" of the interview partner and the "proof" he or she brings to the table. For one conducting such an interview, the following question arises automatically: How to motivate experts for interviews? Several ways exist for how to increase the experts' motivation. I built mainly on "altruism", which is known as the natural will of scientists to help progress by supporting young researchers.

My strategy was to use the instrumental (Littig, 2009) way of gaining new knowledge. This is achieved by anactive exchange of information and clearly addressing the questions and adhering to a rigid schedule. It was essential to gain the knowledge check that could be helpful for decision-making or innovation. Before engaging in any kind of research or ethnographic study where scientists, experts, or élites are observed, we need to understand "hypersensitivity", which according to Dexter (2006) is a possibility perceived by the expert of the potential of the knowledge being abused in a political, legal or another kind of way.

In order to obtain the best quality data, I tried to collect the most information I could about the interviewees' background and qualifications, as this active way of researching the interviewees is convenient for social science, according to Whyte (1984). Another important feature when interviewing elites is to make them feel comfortable enough to speak their mind. In this respect, they should also feel that the interviewer is on a similar level of intelligence. Pfadenhauer (2009) states that when interviewing experts, the interviewer becomes a "quasi expert". In my case, it would be very brave to say I became a "quasi expert", but what I can say is that I was well prepared for the interviews, as I studied the topic of my research carefully, and I also gained more and more knowledge from every interview Iconducted. According to Dexter (2006), expert interviews are tricky things to do, and the best way to conduct them is to be versatile and to adjust the interview depending on the situation. The "right way" of how to do such an interview does not exist. A sort of abstraction exists in regards to conducting any kind of interview, and for the kind of an interview Schütze (1997) proposes, the setting must be as informal as possible in order to free the narrative.

Trinczek (2009) sketches two heterogeneous ways of interviewing: the discursive and the argumentative. I found both of them convenient for conducting my interviews, especially when dealing with experts/élites. It is important to point the intuitive dimension of the conceptualizers of 4D printing. Expert knowledge is also awarded a central role in modernization theory. Trinczek (2009) discusses the changes in the modern world from the point of view of knowledge dynamics rather than their side effects. Expert knowledge is a part of "institutional reflexivity" (Giddens, 1991).

In getting my research question about different forms of "imagined futures" for 4D printing and its conceptualization by thedesigners of this technology in Austria answered correctly, I first looked for reliability and validity. Good research, in order to bring about some form of a contribution, must have sufficient validity and sufficient reliability. If the validity is low, it is obvious that the research tools have detected something other than what the investigator wanted to find. In this case, even high reliability (if at all possible in this case) is no guarantee for obtaining good data. Similarly, if the reliability is very low, high validity does not save the value of the instrument. Researchers must find (or construct) research tools that are sufficiently valid and reliable.

3.1.2 Focus Group

As a complementary method, I compared the expert interviews with the data gained from the focus group of people known as "hackers". I did so on the basis of looking at "hackers" as a social group who deal with all sorts of new technologies, including additive manufacturing, on a daily basis. I did not choose this group of people by accident. When compared with lay interviews, which I experienced in my previous research, data gained from lay people is often lacks key information about scientific and technical issues.

The aim of this project is to investigate how the future of 4D printing is imagined by hackers who are in daily touch with additive manufacturing in so-called "hacker spaces". This was done by organizing two mixed focus groups which consisted of an equal number of participants. The goal of this project was to answer the questions behind the imagination of future 4D printing technology in terms of possible applications and social transformations brought upon by the technology in the Austrian context.

The method, known as focus groups, is one of the less-frequently used methods in qualitative research in scientific circles. There exists a lot of debate about the suitability, usability, and validity of the data generated by this method. Particularly interesting for me was using this method to obtain knowledge about the experiences, perspectives, and attitudes ofthe participants. This is enhanced by a group discussion and explaining the understanding of the technology and its future in their own words. The aim of this section is to analyze the current state of methodological knowledge, to describe the basic characteristics of this method, its advantages and disadvantages as compared with other methods, and to elaborate on the use of the important principles of focus group to answer the research question. After reading several texts on the subject of methodology explaining focus groups, I have recognized several dilemmas and different approaches associated with the method. I have the impression that researchers who work with this method do so for different purposes: to obtain from participants the kind of information which outside of group discussion might not be publishable, and to gain insight into group interaction opinions to examine the questions raised. In respect to these diverse approaches and different views on the way data collection is being practiced, different ways of analysis and interpretation of the data exist accordingly.

According to Belzile and Öberg (2012), we need to understand that dialogic nature has been always a strong influence in producing socially shared knowledge, and dialogue has represented a multi–voice of the society. We could call it also 'collective voice' or simply something where the opinion is sometimes and, especially in discussing novel technologies, created on the spot by looking for a consensus between participants in the focus group. Another attractive aspect of this method lies in the dynamics of the speed and efficiency of the multi-face and multi-voice of aspects of society, as Markovà (2007) calls them.

3.1.2.1 Characterization of Focus Groups Definition

It is difficult to define where thisdialogic nature of generating knowledge started, and realistically, we can examine only modern times to see clearly and to clarify where and when it began in the past. Another question to ask relates to when people started using the entextualization of the dialogic nature of interaction in group discussions as a source of qualitative research. Bude (2004,) came up with the term "serendipity", which is in his own words refers to *"the discovery of unforeseen, non-normal and unspecific data which require a novel view of interpersonal action and embody a different concept of the social universe"* (Ibid, 321). The term "focus groups" originally started being used by researchers in the social sciences. It was first officially used in 1946 for research on convincing government propaganda in the United States. In the 20th century, several phenomenal intellectuals including Sigmund Freud, Leon Festinger ,and Harold Garfinkel have touched upon this way of obtaining qualitative data for research. In the social sciences, focus groups were pioneered by Robert Merton, who was using this method originally to research reactions to changes in radio programming in 1968.

However, the method was quickly "stolen" and adopted by marketing professionals. For decades, focus groups existed mainly the domain of commercial marketing research. In recent years, social scientists have once again become aware of the potentiL of its use in academic research, and today we can observe two distinct domains regarding focus groups: academic and applied research. In short, we can define focus groups as a form of qualitative research which is based mainly on group discussion. Researchers act as moderators and use group interaction to obtain information on a particular topic with a focus on the insights of the participants, which would be difficult to access outside the group. Due to certain similarities, it should be distinguished from the group interview, in the context of which the researcher is working with several people at once, but the conversation takes place in the shape of pre-set questions which are supposed to be answered by interviewees, and group interaction is not considered as a main resource in obtaining data.

3.1.2.2 Advantages and Disadvantages of Focus Groups

It is necessary to point out the advantages of focus groups in comparison to the two most widespread methods of data collection in qualitative research: participant observation and individual interviews. An important dimension of participant observation is the high degree of involvement in and exposure to the participant's natural environment and the behavior and interactions therein observed. Observation can capture a broader scope and make a greater amount of interaction accessible to the researcher. Compared to participant observation, focus groups are able to capture a larger number of interactions in a shorter period of time, granting the researcher a higher degree of control. It is often difficult to gain access to a natural environment where a large amount of different types of interaction takes place and thus is difficult observe at any one time. Under such circumstances reliable data can be hard to procure, as capturing social and psychological factors such as attitudes and decision-making is made much harder.

Individual interviews (or in-depth interviews, as Leydon (2000) calls them) enable closer communication between the researcher and the informant, and they are relatively highly controlled by the researcher. In an in-depth interview, the observation is focused on the views shared and brought up by the informant.

3.1.2.3 Uses of Focus Groups in Research

The method of focus groups is often seen as a "complementary method" which either precedes other research methods, helps to create and validate research tools, or helps to interpret and evaluate data previously obtained by other methods. However, focus groups can also be used as a stand-alone method of data collection, which reveals not only the attitudes and opinions of participants but also penetrates them, confronts their experiences and perspectives, and keeps track of mutual reactions involved. Another option is to use it in combination with another method: for example, individual interviews, participant observation, opinion polls, or experimental methods.

3.1.2.4 Preparation/Design of Research

The success of the focus group method depends on many. The key to its efficient use lies in the quality of training in research design and a thorough research plan. In the first place, it is necessary to evaluate the following three aspects of research. The first of these are ethical issues: as the debate is largely recorded live, it is necessary to consider that potential time savings may come at the expense of detail and the analysis of the overall quality of research. Focus groups as a method have no set rules for determining the frequency of the involvement of the researcher in the discussion. In this project, I myself tried to significantly affect the quality of the data by engaging with the participants.

Another important issue is the level of involvement in the discussion on the part of the interviewer structuring the debate. In practice, often the involvement of the researcher results in asubstantial penetration of the discussion, as well as the standardization of the occasional deviations of the focus group, especially in serious projects which, at the end, should bring about a solid outcome for the researcher. Structured group discussions are more easily compared with each other, and they also provide data that are interesting for later analyses. However, in these contexts there is a risk that data will be limited by the structuring of the questions and the input of the moderator. This is especially a risk for exploratory research—research conducted about an issue that has not been defined and is still in its theoretical stadium. These kinds of group discussions may be preferable as less-structured approaches with a less-committed moderator, allowing the participants to focus the discussion on priority topics which are in the interest of the focus group by choosing the topics they consider important. However, analysis of the unstructured recordings is considerably more complicated than in the case of structured focus groups.

3.1.2.5 "IMAGINE"

A middle ground between the two approaches to focus groups may be found through a called "IMAGINE".

After asking hackers all the same questions and sub-questions as the experts, I used the method called "IMAGINE" as a complementary and experimental methodology for generating data. "IMAGINE"allows participants to begin speaking freely, and gradually moves on to more structured debate and the specific issues that are the subject of the research. At the same time it does not involve the moderator in the discussion to the extent where he or she can strongly influence or navigate the group discussion. In this project, I brought cards to the focus groups, consisting of quotes by scientists, politicians, activists, and lay people. I was heavily inspired by the work of Felt, Schumann, Schwarz, and Strassnig (2014) and their work on "A Card-based Public Engagement Method for Debating Emerging Technologies", where the method "IMAGINE" was used.

"*Cards have frequently been used as stimuli for debate and as research tools in qualitative research as well as in public engagement with science and technology*." (Felt, Schumann, Schwarz, and Strassnig, 2014 , 5).

As mentioned earlier, this method has many great features, and one of them is that the moderator stays in a passive role while at the same time offering cards with quotes by scientists and politicians, as well as official information from different media. This situation, described by Felt, Schumann, Schwarz, and Strassnig, (2011), turns the source of the information virtually present without being physically present. In my research, during these short meetings, the groups discussed several topics and thematic areas related to 4D printing.

In these focus groups, I played the role of moderator. Nevertheless, I only made introductions and encouraged the participants to choose new cards if the debate was stagnating and not offering any new insights. Before I played this role, I knew I needed to be well prepared. According to Hydén and Bülow (2003), it is crucial to create "acommon communicative ground" to avoid problems in the interaction of the group.

The discussion about the future of 4D printing progressed through several phases:

1.) Opening of the meeting. I briefly presented and explained the research question, described the topics that were supposed to take a position of focus in the focus groups, and briefly related the rules that the discussion ought to follow regarding the use of "IMAGINE".

2.) Kicking off the discussion. Conversation rarely starts spontaneously by itself; it was necessary to induce a group atmosphere and start discussions on the subject and agree on the way in which participants would choose and shuffle the cards.

3.) Process of the discussion. As mentioned above, this depends on the extent of moderator involvement. My role laid mainly between curbing the participants from straying too far from the topic at hand, encouraging quieter participants to present their views, preparing the cards and so on.

4.) The official conclusion of the discussion. The participants must have a clear understanding of where and when the debate ended. It was useful to ask each group member for a summary of the results of the meeting, as these summaries helped me to identify more clearly which topics were considered important by the group, and what their final views regarding 4D printing and its imaginations ofthe future were.

3.1.3 Grounded Theory Method (GTM)

This chapter explains why exactly I have chosen the GTM, how it originated, and in what aspects it constitutes the analytical methodology applied to the data examined.

Qualitative research involves many ways of examining and interpreting data, but for my research I have chosen the method called grounded theory because I find it the most convenient. As the name implies, it is a method for creating a hypothesis or theory that is grounded directly in empirical data. In other words, it is a theory inductively derived from the phenomenon it represents and investigates (Strauss and Corbin, 1990). The fact that it was created inductively means that we are not starting with a preexisting theory to be verified, but rather by collecting the data on which the theory and the analysis are based in a mutually complementary manner. In the context of my research, this means that although I had some assumptions based the literature on the subject, I tried to analyze the data I collected as objectively as possible. In other words, I let them speak for themselves. This is an important aspect of the theory, which I will explore more in the section dedicated to Theoretical Sensitivity.[15] Strauss and Corbin (1990) emphasize that theoretical sensitivity is not something a person is simply born with—rather, it is necessary to continuously improve one's theoretical sensitivity over a lifetime. It is something which needs to be looked at throughout the whole process of research, mainly because it allows us to dispassionately look at data while the researcher is able to constantly ask questions, seek answers, and develop their analytical thinking. The greatest advantage of this theory is that if it is intertwined with the everyday reality of the empirical world, and if it is carefully and inductively derived from various data, then it ought to be comprehensible to the people working in the field. Thus, grounded theory makes it possible to influence the phenomenon studied. Examples of both good and bad attempts at grounded theory are given by Glaser and Strauss (1967), who develop four basic criteria to assess the suitability of the theory for the phenomenon: consistency, clarity, generality, and control.

The creators of this method are considered to be Barney Glaser and Anselm Strauss. While both of these pioneers came from a different philosophy, each made significant contributions to the origin of GTM. The method is also significantly influenced by Paul Lazarsfeld (Strrauss and Corbin, 1990). Glaser and Strauss's research, pioneered in Chicago and at Columbia University, sought to ensure that research be useful not only for professionals but also for lay people, resulting in their first collaborative research project which dealt with dying (1965, 1968). I see this original goal of GTM as very important, and, because of this, I conducted my analysis with the aim of making it intelligible for the experts and the hackers alike, while at

[15] See Chapter 10.2, Theoretical Sensitivity

the same time seeking to encourage new practical applications and a deeper understanding of this revolutionary technology. This aim is explored in Chapter 6 : Grounded Theory.

The GTM consists of a set of techniques and procedures that exist to establish the theoretical expression of the studied reality and the research question, which is exactly what I want to focus on and what I want to investigate about the phenomenon of 4D printing. In the context of my research, this reality is the future development and shaping of this technology in the Austrian socio-technical context, focusing on the attitudes and expectations of actors who come into direct contact with the technology and are thus crucial in influencing its future development. The procedures described by Strauss and Corbin (1990) have been omnipresent in my work. In the following lines, I am going to describe the software that I used in the creation of a GTM for processing qualitative data.

3.1.4 Scientific Software

In this chapter I will examine how computers have began being used for the purposes of qualitative research, on what it means to work with CQADS, and on how the program Atlas.ti contributed to my research.

Qualitative research as a social movement was originally a radical response to the dominating orthodoxy of quantitative research methods. This included rejecting technological statistical work which was seen as a tool of dehumanization and excessive control, rather than as intellectual exploration (Silverman, 2011). In the context of Actor-Network Theory (ANT), the computer has been recognized as a significant non-human actor that affects almost every sphere of human activity, and social studies have not avoided this trend. Unlike researchers, however, a computer by itself does nothing. Working with such non-human agents is always based on interaction. In this sense, we can understand computers in the context of post-structuralism. We can see this resource as something peculiar and unpredictable, which is not deductible (Konopásek , 2007, referring to Latour, 1994). The computer gives us the possibility of processing a great amount of data, as well as of outperforming the original techniques of information handling and the systematic classification of data. Based on a recommendation from my friend, I decided to use the scientific software Atlas.ti, which I used over the entire course of my master's studies and which is well-suited for qualitative research. However, Atlas.ti also includes many quantitative tools. The quantitative tools include, for example, the world cloud which indicates the frequency of the use of particular words in a document. Now, I am going to try to explain the principles of working with the software Atlas.ti as well as its tremendous importance on the development of my grounded theory. The computer first symbolized what was seen as negative about quantitative research by qualitative researchers: that technology would bring alien thought into research. This prevented researchers from objectively evaluating the advantages and disadvantages of working with previous programs similar to Atlas.ti, such as CAQDAS (computer-assisted qualitative data analysis) (Silverman, 2011).

Silverman (2011) also said that while this program was very dubious at first, the technology has moved forward and been further developed over the past few years. Konopásek (2007) has chosen to give a broader perspective to working with this program. According to him, Czech social scientists have expressed the view that Atlas.ti is an excellent and a unique program, with which I fully agree. Konopásek (2007) points out the advantages of the graphical environment offered by the program, allowing for access to a variety of multimedia formats. This permits for the processing of non-quantifiable (qualitative) data while using intuitive operation. Nevertheless, the one big drawback of the program mentioned by Silverman (2011) is a double-edged sword. That drawback is that is that while experienced researchers can make great use of the program, there are too many tools for an inexperienced investigator to successfully operate. My advantage was that I had worked with the programs through the whole of my studies in processing study materials, which allowed me to control these tools when working on this thesis. It was especially helpful to have my literature at hand in a systematically processed format.

3.2 Materials

3.3 Six Expert Interviews and two Focus Groups with "Hackers"

3.3.1.1 Six Expert Interviews

In this chapter I am going to explain how I conductedthe expert interviews. All the expert interviewees and their occupations were anonymized as I found it convenient for this kind of project. In place of their real name I used randomly generated pseudonyms, which were created by a name generator.[16]

The main advantage of these expert interviews, which played a major role in my mission to answer the research question of ***"How are different forms of "imagined futures" for 4D printing being conceptualized by the designers of this technology in Austria?"***, was the high concentration of and accessibility to the materials I was interested in. In addition to this, I gained access to the field, as well as information for investigating scientific collaborations at the X University in Austria, well known for its recent successes in developing additive manufacturing. Its contribution to the acceleration of 3D/4D printing technology has been one of the most prominent ones of this field.

Based on the interview data, I focused my analysis on the general workflow and efficiency of the generation and transfer of information and knowledge. I am interested in different kindsof collaboration, in the differences between various types institutionalized and non-institutionalized collaboration, and especially in the future of this style of working in academia in the Austrian context. I had luck in establishing great field contacts. To be more specific, my primary field contact and first interviewee was Dr Scot Benedetti, who engages in various kinds of collaborations in the scientific community with a focus on the implementation of smart materials in 3D printing on a daily basis. Dr Benedetti comes from a background different to additive manufacturing: his original field is that of polymer chemistry. Nevertheless, his contribution has played a crucial role in the development of 4D printing. Dr Benedetti played a key role in opening the doors to the possibilities of 4D printing in Austrian academia, and has worked to untangle and unify the network of prominent experts dealing with 3D printing in Austria. Firstly, he introduced me to another key person at X University in Vienna, Dr Emerson Lewko.

After getting to conduct such an important interview with a highly prominent participant, it was easier to network with more scientists whose main focus is on additive manufacturing. I established meetings with two important university alumni who are currently

[16] See web page http://namegenerator.biz

running a fast-growing company called "L". The first interview with the company "L" was conducted with the CEO of the company, Dr Luce Cuesta. This interview yielded some very interesting data. The second interview, conducted with Dr Kenneth Hyams, I consider one of the most beneficial.

The last two investigations were completed firstly by way of meeting with Ing. Betsy Vogele, CEO of the company "H", whose work is primarily concentrated around helping interdisciplinary research with the implementation of 3D printing. The last interview took place again at the X University in Vienna with Dr Haywood Sonquist, who is the CEO of company "S", whose primary focus is on incorporating additive manufacturing to biomedicine and custom printing for medicinal purposes. These last two scientists were not Austrian but Slovak. However, they are actively contributing to research in Austria as well as collaborating with Austrian scientists. For instance, Dr Sonquist and his company "S" are developing a new application for 3D printing together with company "L". Also, Ing. Betsy Vogele is an active contributor at 3D printing meetings in Vienna, and the majority of clients of company "H" come from Austria.

While it was quite challenging to establish convenient contacts in the academic world, it was even more difficult to find "hackers" with considerable knowledge on the subject who were willing to participate in interviews. While searching for more contacts, I deployed myself in so called "Vienna 3D printing meetings".

The following table represents the content of the expert interviews, and more information can be found in Chapter 4.2.1., Experts and their Focus.

Expert Interviews			
Expert	Occupation	Specialization	Length of Interview
Dr Scott Benedetti	**Award winning scientist, Institute of Applied Synthetic Chemistry at University X in Vienna**	**Polymer chemistry, material science, additive manufacturing**	**1 h 42 m 37 s**
Dr Emerson Lewko	**Scientist, head of the department of "Y" at University X in Vienna**	**Polymer chemistry, material science, additive manufacturing**	**1 h 17 m 25 s**
Dr Luce Cuesta	**CEO at "L" GmBH**	**Additive manufacturing**	**16 m 42 s**
Dr Kenneth Hyams	**Board of European Students of Technology, "L" GmBH**	**Material science, additive manufacturing, polymer chemistry**	**2 h 2 m 53 s**
Ing. Betsy Vogele	**CEO of "H"**	**Material science, additive manufacturing, architecture**	**2 h 40 m 26 s**
Dr Haywood Sonquist	**CEO of "S" and university professor at "X"**	**Biomedicine**	**1h 48 m 22 s**

Table 1.0 Interviews with the Experts

3.3.1.2 Focus Groups with "Hackers"

In this chapter I am going to discuss the process of finding the hackers, as well as elaborate on the anonymization of the data gathered.

I think one of the natural qualities of young people is a hunger for knowledge and the desire to test their ability. Upon these positive characteristics of young scientists, the project "Vienna 3D printing meetings" was built.

The basic objective of the project "Vienna 3D printing meetings" is a search for talent and promoting interest in the study of the progress of additive manufacturing. An additional goal is trying to find independent solutions for the issues in the scientific development of the technology. In fact, this has led to teamwork and efforts of informal collaboration amongst participants. In order to adequately attract young students and freelancers, the event provides them with the opportunity to participate in problem-solving with teams of experts from international scientific collectives, working with the latest technologies and practices. "Vienna

3D printing meetings" works with students, scientists, and lay people alike, and is held on monthly basis. In this case, we could compare this phenomenon to a certain form of free "participatory collaboration" (Chompalov, 2002). An important reason for this comparison is that these people seem to have different approaches to understanding the issues at hand, and are thus able to offer different and valuable points of view.

Research also takes place where technology is not only being created through the collaboration of certified scientists, but also by lay experts. "*Boundary crossings between amateurs and professionals have a long tradition. In natural history and astronomy, for example, there has always been a rich exchange between amateurs and professionals*" (Meyer, 2013 , 7).

The "Vienna 3D printing meetings" were where I met my key contact with the "hackers", and after I gained their trust, they agreed to establish a focus group. Their only requirement was to remain anonymous. I have tried to ensure and secure their anonymity by this process.

When processing pre-focus group communications, I used a list of online addresses that I assigned to randomly generated numeric codes. In this unit of this hermeneutical research project, I created a document containing a list of randomly arranged numeric codes which were categorized by the participants' values regarding the different uses of 3D/4D printing. Through the Query Tool (from Atlas.ti), I qualitatively evaluated the data by blending the various aspects of specific participants. Thus I only assessed the values and aspects outlined by the researchers and thus analyzed the participants' views, and in my view, this helped me to properly divide the participants into two complementary groups. After splitting up the participants by codes, I traced the online address back to the participants so that I could invite them to the appropriate focus group. This list was subsequently destroyed, which assured anonymity for all participants.

Luckily, I managed to connect with some very interesting people who work with 3D/4D printing. The spectrum of participants was really wide. It ranged from home DIY hobbyists and students to engineers and designers for advertising agencies, from artists to architects. I eventually divided the participants on the basis of whether the technology was their main focus or if they worked with 3D printing alongside different technologies. Another dimension of the distribution was according to whether they considered themselves to be dedicated to this technology in the workplace or used it in a more private setting. The final aspect of the division was on the basis of what their expectations were for this technology. They were divided into groups based on whether they assumed the technology was going to spread to become a household item, or if they thought that it would only be used for industrial purposes. Their views regarding the potential risks and benefits associated with the technology were also taken into account. The first group, A, was made up of participants whose main interest is in 3D printing, and who have very positive expectations for this technology. These were the students, the engineers, and the designers. The second group, B, was made up of participants who, while dedicated to this technology in private, and have a rather negative view of the future development of this technology. These were the enthusiasts, the inventors, and the artists. The participants who did not fit into either group by default or diverged by only a small deviation from the center were divided randomly between the two groups.

3.3.1.3 Transcription

"*Transcription does not replace the video recording as data, but rather provides a resource trough which the researcher can begin to become more familiar with details of the participants conduct.*" (Heath and Hindmarsh, 2002, 109)

When transcribing the recordings I have applied the GTM as well as coding techniques are described by Strauss and Corbin (1990). For more information on how I conducted the coding by using Atlas.ti, see the appendix and Chapter 10.3, Conceptualization by Coding.

The analyzing of the data obtained by focus groups is in many ways similar to other types of qualitative data analysis. The first step of the analysis is a detailed transcription of recordings (audio, possibly accompanied by a transcript of nonverbal expressions from video). The transcript from focus groups, of course, always has its own characteristics, and it is difficult to assign specific participant statementsto particular individuals as not all statements are made clear and distinct at all times. Other problems can occur as well, such as multiple participants talking at once. The transcripts are coded with a method similar to individual interviews. The method of data analysis depends on the research objective, as well as the composition and structuring of the groups.

An important question for me to ask before adopting this form of qualitative research and analysis was whether the basic unit of coding should be separated individually or coded as group. In this project, the coding was done with the basic unit as a group that consisted of individuals and the various interactions between participants. This also touches on the framework through which we can look at the different interactions of the participants via Actor-Network Theory. The theory was formulated in the second half of the 1980s by a group of French and British sociologists and philosophers (Bruno Latour, Michel Callon, and John Law, to name a few). It deals with the study of the world as a heterogeneous network: a network of "designs". Heterogeneity means understanding the world as composed of a diversity of various relations, and design refers to the idea that the world is in a constant process of its formation, affected by a number of different entities.

The following table represents the focus groups, and more information can be found in Chapter 9.4 (Hackers, Group A) and 9.5 (Hackers, Group B).

"Hacker" Focus Groups			
Hackers	Specialization	Status	Length of the Focus Group
Group A	**Additive manufacturing, material science**	**Closer to the experts. Working with 3D printing in their jobs.**	**2 h 2 m 46 s**
Group B	**Design, visualization**	**Critical of experts. Searching for new applications.**	**2 h 34 m 3 s**

Table 1.2 Focus Groups with the Hackers

4 Research Question

This project investigates how, in the Austrian context, the future of 4D printing is imagined for everyday life uses by the institutionalized engineers and the non-institutionalized "hackers" shaping the design process of the technology. The main research question of this thesis is as follows:

How are different forms of "imagined futures" for 4D printing being conceptualized by the designers of this technology in Austria?

More specifically, the main aim of my project is to investigate how the future of 4D printing is imagined by the designers of this technology in terms of possible applications, social transformations, and regulation in the socio-technical context of Austria.

4.1.1 Sub-Questions

The focus of my research lies in the development and direction of 3D/4D printing technology, which is not widely known among "lay people" nor used by Austrian lay citizens yet. Thus I had to focus my research on actors who commercially operate this technology every day. While scientists hold expert knowledge, to gain valid information from the interviews I had to be able to pose appropriate questions. Appropriate questions were also essential during the course of the focus groups, since they had a significant effect on directing the discussion.

Asking sub-questions in qualitative research is a dynamic process because the questions become more poignant and relevant as our Theoretical Sensitivity[17] increases. Strauss and Corbin (1990) describe the process of laying down the theoretical issues and increasing sensitivity by reflecting on what we want to target, and thus what we want to explore in the scheduled social reality. In the context of my research, such efforts can be expressed by the following question:

How are different forms of "imagined futures" for 4D printing being conceptualized by the designers of this technology in Austria?

This question is asking for a conceptualization of the technology as this is precisely what is essential for the development of any given technology. The technology of so-called "4D printing" is intertwined with socio-technical controversies which emerge from the wide applicability of this technology. It also encompasses differing views from scientists from the same field, depending on their focus and individual interests. I had to take these contradictions into account in the research to ensure not getting lost and producing reliable results. The most important of these problem spots was the relationship between the scientists and the hackers to

[17] See Chapter 10.2, Theoretical Sensitivity

industry, and the relevant legal regulations consisting of policy therein. The processes and methodologies employed in this project offered a suitable frame for investigating the views of the actors who are the most important in implementing this technology in the Austrian context and, who thus shape the future.

The conceptualization of a technology is a complex process which due its abstract character needs to be deconstructed into its various components. An important aspect is the views of designers and their definitions of a given technology. On this basis, in order to reflect the ways that the designers envision the technology being utilized in the future, I ask:

How are visions of the future and expectations of 4D printing being imagined, created, and defined by designers of this technology?

Scientists and hackers are actors who are familiar with current advancements in technology and understand their significance. By relying on a knowledge of the reality of technological development, they can better understand potential future effects on science, industry, and trade. Hence, these people are able to observe certain technological trends earlier than rest of the society. Understanding their view about current trajectories is fundamental for revealing possible future developments in the technology of 3D/4D printing**:**

How do conceptualizers of additive manufacturing in Austria see its potential for shaping society in terms of potential (every day) manufacturing, work/industrialization in the near future?

Knowledge of the current direction of technological progress provides insights into how the technology may encounter and influence society in the future. To understand this relationship, we must first understand for whom this technology is primarily intended. Distinguishing the actors who use 4D printing technologies and the methods by which they are utilizing it is necessary for understanding the relationship between society and the technology**:**

What kind of users is this technology (principally) designed for?

Since this is technology is still evolving and its applications are yet to be firmly established, a major focus is on its production and development. Its wide applicatiom involves this technology in a number of diverse branches of research and production. Scientists are dealing with the invention of novel methods in the use of this technology as well as inventing production processes by which this technology can print new materials or shapes. Conversely, hackers deal with inventing different possibilities and applications that are not often directly exemplified by the manufacturing process. Thus their particular focus is on the practical uses of this technology for various purposes.

What are the lines of research in 3D/4D printing?

at: **a) X University in Austria**

b) Austian Company "L" Gmbh

c) Ausitrian Company "S"

d) Slovak Company "H" SRO

e) Austrian Hacker Space

Innovations and inventions are influenced mainly by the scientists who invent new technologies. Innovations, however, are also influenced by their users, who are in turn influenced by technology. In the case of 3D/4D printing, the technology has the potential to influence the development of society and to bring about various social implications through the future possibilities on offer. The applicability of this technology is extremely wide, and paradoxically, the terminology chosen by MIT when naming the technology "4D printing" has now been met with disagreement.

I have attempted to determine what the thoughts regarding this terminology are as regards the Austrian actors studied over the course of this project; to determine if the terminology of is respected among Austrian scientists, and how well the participants are informed about the technology. This is because the most problematic aspect of the research appears to be the concept originally introduced by the MIT scientists—that of 4D printing. I thus ask:

Do Austrian experts and hackers agree with the terminology chosen by the MIT with regard to naming the technology "4D printing"?

The new possibilities arising from the use of additive manufacturing and smart materials can have a major impact on society in the future. Another potential influence that ordinary citizens may feel may be the emergence of new products that may significantly affect the appearance of today's market. The effect of the technology on the market mainly consists of the production process. Accordingly, I tried to investigate the relationship between the 3D/4D printing industry and its potential social implications. The arrival of additive manufacturing can be viewed as the arrival of a third industrial revolution (Rikfin, 2011). In this work, I sought the views of the conceptualizers regarding the arrival of this technology as the "third industrial revolution": **Do experts and hackers agree about the question of 3D/4D printing constituting the start of a new industrial revolution?**

The technology of additive manufacturing demonstrates great potential for innovation, which can and probably will become omnipresent in society. This carries with it the potential risk of possible controversy that may arise through the discrepancies between the current socio-technical ideas and a new technology. I have tried to explore this possible controversy which may arise in implementing this technology by asking:

4 Research Question

What controversies could be caused by the technology of 3D/4D printing in the future, and why might this be the case?

The contradictions between dated socio-technical ideas and a new technology can bring about a very real possibility of risk. A part of implementing 3D/4D printing is the way in which this technology is anticipated to work and benefit its users, as well as predicting the risk of diversions hidden in the technology. For this, I tried to investigate how the use of this technology may one day look in practice, and what the risks of abuse that may arise during practical use are:

In what ways and by what kinds of intentions could 4D printing technology be used in the future?

Any technology can be abused, starting from Paleolithic hand axe to the atomic bomb, and as additive manufacturing of smart materials demonstrates, with 4D printing there is also an increased risk of abuse owing to a wide spectrum of potential applications. The designers of this technology are the ones most visibly confronted with the possible risks associated with this technology. Their view of the technology may hide the key in understanding the necessity of legal regulation and its possible transfer. It is necessary to understand how such control can be realized and what effects it may bring. Thus, lastly, I ask:

How are the conceptualizers of 3D/4D printing imagining the regulation of the technology in the future?

5 Analysis and Interpretation of Data

In this chapter, I am going to analyze the research data generated with the experts and the hackers. Both groups of participants are going to be elaborated upon in detail, and I will impose a particular focus on their specific characters. These data are further analyzed by using STS concepts.

5.1 View of 4D Printing by Experts

In this chapter, I am going to delineate the experts' views and sketch their attitudes towards additive manufacturing. The group of six scientists was not completely homogeneous, since in different sectors of the field, the researchers all deal with different issues. The experts interviewed came both from academia and from the commercial sphere. For the most part, these two areas overlap and demonstrate the connection between the two sectors. They do, however, articulate different foci. All six of the experts deal with using this technology in a huge range of applied contexts, ranging from chemistry to metallurgy, and from biotechnology to biomedicine and material science. The fact that additive manufacturing is omnipresent in all these field showcases the multi-functionality of this technology, and it is one of the reasons why I consider it necessary to at least briefly outline the focus of the experts and their opinions on the technology they have chosen to specialize in.

I am going to follow this up by elaborating on the controversies faced which originated from the differences in the experts' views. The most obvious controversy was the name of the technology and the general terminology, owing to the lack of a single, widely recognized name, as I have outlined in Chapter 10.3, Conceptualization by Coding. The current use of this technology is more or less consistently agreed upon, but the experts' views on the future development are full of controversies. These disagreements were mostly about the control of the "script" or "in-scribing", or indeed, the way in which technology should or should not be regulated, especially with regard to the effects on society. Other important notions covered the misuse of technology as well as the potential environmental and economic impact of the translating this technology into practice. On the other hand, important differences of opinions were raised in relation to the possible negative effects of too much regulation on the development of this technology. Regarding the assumptions about future developments, the experts differed slightly. No two matched perfectly in their views, but all of them agreed on one point: the future development of the technology depends on the way 4D printing is framed today.

5 Analysis and Interpretation of Data

In addressing the controversies mentioned above, I am going to get into more detail in order to make it clear to the reader how my arguments are grounded in the data. Controversies are going to be separated into three units. The first unit is going to deal with how the technology is being framed right now (in 2016). Additive manufacturing technology has many uses that need to be briefly mentioned, as the meaning and the dimensions of this technology should be made understandable to properly showcase the ways in which this technology interferes with the functioning of the world. These dimensions are essential for describing possible future technological developments. The second unit will deal with the research on this technology and the "inscription" (Akrich, 1992) that scientists insert in technologies during their development. Shifting the research is essential to indicate in directions in which the technology is likely to evolve in the future. Since scientists are key actors in the development of technology, it is necessary to monitor the "inscription" which is being inserted into the technology and in this capacity predetermines the technology in regards to its use and the future users of the technology. In the third unit, I am going to continue with "black-boxing" and the ways in which this technology could be controlled or possibly exploited by using "de-scription". Regulation is a necessary part of "inscription", and with this particular technology it is questionable whether it is even possible to regulate its development, or to what extent regulation is desired within the parameters of current legislative and social settings. In the context of "de-scription", it is essential to explore whether or not the misuse of this technology can or cannot be prevented, and to what extent this possible future misuse may be dangerous.

At the end of this subchapter, I would like to recapitulate all the facts known in the present moment and take note of some of the links between the different aspects of this technology. I am going to also address the dialectical relationships between scientists, society, and technology. The scientists or experts who were interviewed will be positioned in the imaginary conceptual structure that is going to help to better understand the technology and the importance of scientists in this particular context. At the same time, I am going to focus on comparing and contrasting the different emerging views and their justification.

5.1.1 Experts and their Focus

As demonstrated in the chapter on materials and methods, I started my research at the Institute of Material Science and Technology whose primary focus is on additive manufacturing and other related technologies. After conducting interviews on the academic floor, I continued my research with companies "L", "S", and "H". All of these companies deal with the development of new materials or new applications of additive manufacturing. The applications of additive manufacturing are spread very wide. At the moment, applications are mostly present in chemistry, biology, and architecture, as the use of interdisciplinary collaboration is gradually expanding.

The technology of 3D/4D printing has a broad scope of applications that deal with non-existent social norms which could create a black-box for safe and standardized uses of the technology. We can observe this phenomenon in research alongside the attitudes of individual scientists as regards the technology. This technology can fundamentally disrupt our view of the world—at the same time, however, our view of the world frames the future development of the technology. In other words, we need to look at this phenomenon through the idea of "co-production". Because this technology can be thought of as transformational, the missing framing may cause the technology to run rampantly out of control. The considerations I sketched in this paragraph are going to be elaborated in Chapter 5.1.2, Evaluation and Connection to Concepts (Mindset-Shifting, Inscription, Critique of Term Programmable/Third Industrial Revolution , Engineering Technology, Regulation/De-Scripting and Black Boxes) and will be further developed in light of the interpreted data. Now, I am going to briefly present each expert separately, along with the attitudes, expectations, and descriptions of the targeted research of the expert interviewees. Although the experts are different in many different aspects, they have one thing in common: they are skeptical.

5.1.1.1 Dr Scott Benedetti

Dr Scott Benedetti works in the interdisciplinary fields of polymer chemistry, material science, and additive manufacturing. Interdisciplinary collaborations with experts of the highest caliber from various fields make up his everyday bread. Dr Benedetti is known in the scientific world owing to his contributions in prestigious scientific journals, as well as by virtue of his fundamental work in the production of additive materials as sponsored through the Marie Curie Grant. Originally, Dr Benedetti did not deal with additive manufacturing—rather, this is where academia and the development of the "market" brought him. His focus liess the field of photopolymerization and biomaterials. To be more specific, his primary focus iss on trying to invent a monomer usable by 3D printers that will be the least toxic among the monomers employable for such use. Toxicity plays an important role in the research of applications of complicated fractures in medicine. Dr Benedetti's research in interdisciplinary collaboration can be better demonstrated in the following words:

"*The research being highly interdisciplinary requires large team of different experts. As a polymer chemist, I work on the development of reactive low toxic monomers, which are used for the 3D fabrication of the polymeric scaffold. Mechanical properties of the final biocompatible polymer is characterized by materials scientists. Collaborating engineers constructed a photopolymerization based 3D printer appropriate for their needs. The scaffold is not a spare part and must provide a* *host environment, where stem cells can differentiate and proliferate. Thus the selection of the stem cells and their interaction with the material and scaffold in vitro can only be done by cell biologists. Finally, medical doctors test the scaffold seeded with or without the stem cells in vivo. Needless to say, that at any step an extensive interactions between different experts is required although the tasks are performed separately.*"

Dr Benedetti originally saw huge potential in additive manufacturing. He was not only completely aware of the technology's capacity to save enormous amounts of material in the manufacturing of any matter whatsoever, but also of its potential to influence everyday life through various social implications associated with countless new opportunities. In addition to medical uses, Dr Benedetti sees additive manufacturing as something that may be widely used in architecture, and he does not find it surprising that at the same time, MIT department of architecture goes hand in hand with the department of additive manufacturing. The key point is that in the architecture of additive manufacturing, there exists great potential in both the two key features of visualization: in the restoration of historical monuments as well as in designing of new buildings, and equally, in the indispensable opportunity of creating miniatures of buildings or bridges with nano-precision, where investors and various experts can see how the final structure will look, which can help them to better assess the suitability of the object in reference to various locations and circumstances.

The idea of printed material having self-assembling properties given rise to by using 4D printers seems very interesting, but what is still lacking is a specific mechanism, a kind of a fifth dimension allowing the product to be folded back. This is an important aspect of any technology associated with "action", since it follows that if something is capable of folding itself, it has to be able to also unfold as well. In other words, there is a hot debate about the problem of how to create the right conditions for disassembling the printed material or desired product after it has performed its function.

Dr Benedetti: "*So additive manufacturing had and have always an important role in architecture. When we take in to account 4D printing and what can be demonstrated with it nowadays, than if the prototypes will keep developing in the same way they do now that they keep accelerating than maybe we can expect the furniture which will build itself and we never ever will need to spend an hour with a screwdriver to try to put the furniture together from the plan. It seems realistic regarding to existing prototypes, but it's mainly a question of time and question of how the scientist find the way of assembling back, Because there is nothing worse than a huge sofa in a flat on the 5^th^ floor, which you can put back to small pieces when moving out from the flat* [laughter]."

Let us dig deeper into the concept of the 4D printer, and let us explore the terminology a little bit more. Dr Benedetti has dealt with similar characteristics in materials as described by the scientists from the MIT, but interestingly he had not encountered the term "4D printer" before I approached him for a meeting through university e-mail. I was faced with a similar reaction from some of the other experts, and this is why I am going to address in depth the controversy of calling a thing by different names, or using the one name for different things.

In Dr Benedetti's view, the introduction of the term 4D amounts only to a "buzzword", and the terminology is misleading because the technology is not as novel as it is being lauded as by the MIT. In Dr Benedetti's view, introducing this phenomenon with the name "4D" printing has only been a way to create something more attractive for investors, and about trying to attract more investments to their research. In this case, the researchers from the MIT, by introducing the term "4D", have set the course for the additive manufacturing technology of smart materials. However, despite Dr Benedetti's opinion, there is nothing about the technology itself that does not amount to a really great discovery.

"*So 4D printing, the term is to a certain extent only branding, something like when Pepsi introduce Pepsi Max or Pepsi Cherry. It's a way how to alarm people that there is something new in the market, but many times also like in this 4D printing, it is not absolutely true that a new thing has been developed. The truth is that the MIT department of additive manufacturing and architecture started to focus more on the developing of smart materials and its possible applications via 3D printing using time for self assembling and they called it 4D printing because its an attractive way of calling it and it can potentially get also more investors than if they called it the 3d printing of smart materials or fuse deposition modeling, which can assemble itself et cetera*."

Another controversial expression in the language used in introducing this new technology is, in his opinion, the notion of "**Chyba! Nenalezen zdroj odkazů.**"[18], which to him evokes the image of someone coding something on computer, and for the technology working simply on the basis of that. This is not quite so, as biological rules are used to manage the reactions that control "programs", and as such, act as a sort of an interface between the programming and engineering, and the use of physical and biological laws.

"*Yes, it mainly uses biological rules to assemble the wanted shape or value, but, at the same time, it uses biological rules with the combination of computer programming. This means that it's both but also neither of them because in the programming, if we take for granted that this term in this relationship means that we use a computer, we are dealing with engineering. Results usually are not so exciting and progressive in additive manufacturing at the moment, so things are becoming much fuzzier and unexpected. In the issue of 4D printing, we can observe both engineering and biology go hand in hand in creating something absolutely new.*"

[18] See Chapter **Chyba! Nenalezen zdroj odkazů.**, **Chyba! Nenalezen zdroj odkazů.**

Dr Benedetti has contributed a great deal to the development of additive manufacturing, and while he sees great potential in 4D printers, he warns that society needs something more than just a technological revolution. If we look back ten or fifteen years, companies were wasting forests' worth of paper. Today in 2016, almost every commercial e-mail asks you to consider twice before printing out the content. However, this development was unfavorable for many involved parties, and was caused mainly due to 2D printing technology becoming more accessible to the general public after swift developments in 2D printing. When the progress started raising social implications, society began to regulate the generation of waste. By mentioning 2D printing, I wish to look as a futurist on the issue of 3D/4D printing—paradoxically, by looking at the past.

I want to highlihgt the necessity of looking at 4D printing as a futuristic technology so that we can be one step ahead and know to what direction the future will take prior to the development of the technology. This way, society will be ready to regulate it.

"*In my opinion it's time to come up with something, which will not be only a revolution for the human, in the sense that it would create him or her more goods in shorter time for cheaper but in the sense that nature will start to be saved and not wasted enormousl*y."

A parallel between the development of 2D printing and additive manufacturing was supplied not only by Dr Benedetti. Several experts referred to previous technology to a certain extent. Creating this parallel is very fruitful for the analysis, because when we look at the modern way of printing paper, its success can be pinpointed to the fact that at one point in time it became cheaper compared to outdated technology. This ultimately caused an enormous waste of resources Dr. Benedetti assumes that the use of 3D/4D printing is going to impact a huge range of manufacturing sectors and new companies because the capacities of the technology reach far and wide into different sectors of industry. The nature of this advantage is not only in the instant production of almost any component one might want (depending on the complexity of a given 3D printer), but with4D printing it is possible to even create components capable of developing into the required shape.

When we return to the parallels with 2D printing and put healthy futuristic lenses on, according Dr Benedetti, it is necessary to consider whether 3D printing leads to the cheapening of technology and an increase in major pollution by generating new and new products, despite the material in 3D printing creating amazing economical savings (3D printing uses one tenth of material compared to subtractive manufacturing).

"*If additive manufacturing will be cheap and own by many people at home**, then we can expect also loads of wasted material and printed nonsense and this leads us to the point that nature will not be saved much in this sense.*** *And that's why we need to think, before we start to* *even consider to think about possibility of 3D printers to become part of the households, if they will, but that's another question, how can we regulate printing of unnecessary things?*"

Dr Benedetti pointed out the importance of regulating the printing of unnecessary things. I am going to develop this issue and try to answer the question of regulation in the upcoming subsection dealing purely with controversies.

After an explanation of the meaning of an "in-script" and "black-boxing", Dr Benedetti stated that when he looks at the technology, he sees these notions as problematic and remainis skeptical. On the one hand, he recognizes that it is necessary to regulate printing, especially when he thinks of unnecessary objects. However, with regard to regulations in general, and specifically in the case of gun-printing which only requires a printer that is capable of printing metal, he sees no great danger of abuse. This he justifies by:

"*People will always find a way how to abuse any technology. And printing guns will soon become very actual printing as metal will become more available to the ordinary people. We just need to take a psychological standpoint and see that if people want the gun, they could also get it another way and maybe also by less work.*"

At this stage of the development of the technology, he sees regulation as desirable only in terms of the possible ecological impact. Dr Benedetti suggests that any further regulation could prevent the development of technology, and thus it is crucial to construct very sensitive regulatory mechanisms, especially in terms of laws and policies. Although he sees potential threats and misuses of technology, he finds it very difficult to see how scientists could "in-scribe" barriers against potential abuse. Dr Benedetti sees regulation as very problematic, struggling to find a tolerable balance between preventing misuse while at the same time not hindering development. In a somewhat idealistic sense, he sees regulation as follows:

"*I see the future of regulation of additive manufacturing in regulation of commercial printers, so basically the designers of commercial printers would inscribe some stuff which will be not possible to do with these printers and also the law would make a straight regulation for the public so potential hacks would be punished if printers would be abused*."

I am glad that Dr Scott Benedetti was the first expert I interviewed, not only because he helped me reach out to other contacts, but also because he helped me shed more light on the issues at hand. When discussing other expert interviews as well as the focus groups with the hackers later in this work, I will be coming back to Dr Benedetti .

5.1.1.2 Dr Emerson Lewko

Dr Emerson Lewko is the director of the department that primarily focuses on additive manufacturing at the Institute of Material Science and Technology, and is one of the most prominent contributors in the field with some widely recognized inventions. As an example of these, the ultra-high-resolution 3D printer that broke speed-records and set a new world record at the Institute of Material Science and Technology at the Technical University of Vienna can be mentioned. Dr Lewko's research focuses on lithographic 3D printing using photopoliymerization. By collaborating with chemists such as Dr Scott Benedetti, he seeks to create things such as ceramics and digital tapestries.

Dr Lewko's focus is also on the creation of complex materials by applying biological rules for biological purposes, which is also done in 3D printing.

"*We are collaborating loads of with chemistry people but also for biological applications, we are using 'wivo' writing for example and taking cells and write something around them [...] Using special polypac and biological properties, that's one track how to use water based photopolymeraztion or water based chemistry, that's one thing. Chemistry, composite materials ceramics but also 3D printing and engineering structures.*"

Smart materials are generally considered to be the key to success in modern technology because of their greater applicability can help create a safer world.

"*So the material is the key to making things different.*"

Dr Lewko seeks inspiration from nature—or, to be more specific, from the laws of nature. The most interesting element about the laws of nature to him are the self-healing capabilities which organisms possess. For example, we can think about external injuries or the obstruction of blood flow in vessels that may trigger corrective mechanisms which help to maintain the body, as the body itself has the ability to deal with various defects.

If these laws of nature can be successfully implemented in the design of (smart) new materials, then we will be able to produce a variety of technologies that will not jeopardize society through their potential defects, as the smart material will be able to heal itself.

"*What we see happening in the biology if your arteries somehow get block, biology becomes active and tries to solve the things. If your pipes at house get block you have to open everything and replace them all with these active materials really have appeal, because many things will self repair. In the airplanes they meant it to be very expensive maintenance just in case something goes wrong, some cracks appear. But if you have active materials, which do something when things go wrong, that's a really large appeal for many things.*"

Dr Lewko sees the 3D/4D printer and its applications as the future of design, mainly due to the fact that SM/PM can imitate nature in a way that allows them to become fuzzy and more exciting than traditional products.

The day before I visited Dr Lewko, he attended a conference where one of the presenters used a fungus for the creation of desired things. This was a fungus which looked like a tree that was constantly evolving and changing until it finally became a chair that was not unlike a normal chair. Certainly, this process did not look like something that printing with a 3D printer ought to resemble. Nature can cope with things that do not fit into each other perfectly—a quick look at tree roots pushing through pavement shows as much. However, with human technologies such as a car, we must have the exact type of an exact part from the exact manufacturer in order to be able to put the part in the car so that it can perform the required function.

Dr Lewko's vision of the future of design is something like this:

"*Something printed and evolving all the time.*"

For this to realistically take place in the future, there is one important challenge to overcome. This is the ''mindset-shifting'' of society, as people do not seem to be very likely to spontaneously increase their demand for similar, self-evolving technologies in the near future. The consequences of a third industrial revolution (Rifkin, 2011) may allow people to do things we cannot even imagine yet. People want things of a certain quality and form, and the technology of 4D printing is not yet ready for such variability.

Dr Lewko agrees that additive production brings many advantages over the subtractive method of production in terms of economical efficiency and implementing and creating new materials. Thus one might say that additive manufacturing could bring about a new industrial revolution. However, many other methods of production also exist, such as the C & C machine[19]which operates without excess material. Another example of manufacturing is injection molding, where only the exact quantity of material needed for production is injected. Nevertheless, there are also numerous methods of production with a high degree of energy consumption, such as the laser, usually used in working with very expensive materials with a high-energy performance.

First, we must look at energy intensity and consumption, and the effectiveness of the chosen method of production so that we can objectively assess the value of a given production technology.

"*So you have to take the numbers, do the calculations and then you can decide, which one is somehow more relevant ecological or economical, and that's what people will do in manufacturing, because everything cost money, energy cost money. Manufacturing is also very optimized process and 3D printing has benefits there, but we really have to do a path for those things.*"

At the moment, the most optimal material consumption is certainly being demonstrated by additive manufacturing, since the only material is being consumed is the exact amount of material needed for production. The printer prints the desired product by using nano particles. This method can also have more advantages. The biggest advantages of additive production are going to be used mainly in the industry. Nowadays the factories which create many tools, goods, or things comprise a plurality of various components. If stocking spare parts becomes too

[19]Computer Numeric Control (CNC)

demanding and if something goes wrong with a twenty-year-old car, the manufacturer does not guarantee to provide spare parts for repair. This is because there are innumerable types of cars and because there are always new models in production.

Dr Lewko wants to say that the additive method of production gives us the possibility of producing spare parts instantly when necessary. While in everyday life we do not need much planning, in the industry corporations need to plan far ahead in order to optimize production. This means that a tool is usually manufactured once it is needed, or produced once there is a demand for it in the market. However, corporations try to avoid products being stored.

"*So in the future you'll have only your designs in the computer and you can keep them for 100 years, no problem, and then you'll just print it out so there will be really big benefits*."

Dr Lewko sees another benefit of additive manufacturing technology in the opportunity of designing new shapes and in producing new and more complex materials and tools.

He thinks that the future of this technology lies mainly in industrial manufacturing. While hobby approaches are really nice, and it is good for lay people to imagine how things are made, Dr Lewko does not think that the future of 3D/4D printers will emerge in the private sector.

"*But these hobby things will stay as a hobbies. But if you think in terms of market, manufacturing is a huge market... billion or trillions of dollars or euros. So that's what I think is important for 3D printing in the future to provide manufacturing with the suitable tools*."

The main reason why, according to Dr Lewko, 3D/4D printers will not become a part of standard households is that they place high demands on the operator. On one hand, users often have difficulty with 3D design on the computer. Not everyone is able to draw on the computer at the level necessary for 3D printing. On the other hand, there is the difficulty of storing the materials necessary for 3D printing. Therefore it is easier to have things ordered through companies providing services which make use of additive manufacturing, and to have the desired goods sent to one's home through Amazon or another distributor.

"Why would you use twenty different types of polymers at your home and five different metals [...] I think that's a hobby, but it will be relevant for people to buy stuff from the e-shop. So if you need spare parts for anything you'll just order it from the internet and will be printed. Because having a 3D printer at home and be able to use it will mean having tons of unnecessary material[...]In my opinion, it is a hobby and it will stay the hobby, but it's not a future for the people to have it in an ordinary house."

As for regulation and the risk of the misuse of the technology, Dr Lewko's opinion is similar to Dr Benedetti's regarding the opportunity of building a fully functional weapon with a 3D printer at home. It does not matter whether someone shoots another person with a 3D printed weapon or a purchased one, because if someone wants to get a weapon he or she is going to get it one way or another.

"*But actually you could do that now, you just need a small metal and a drill machine, which also many people have at home and they can also make weapons*..."

The manufacturing of these things is also possible without a 3D printer, but the more dangerous thing is that the drawings and plans for these objects are widely available. If thus motivated, one can relatively easily take a drill machine and some additional components and create weapons.

According to Dr Lewko, regulation in these scenarios is possible only through a restriction on gun ownership. If everyone on the street has a gun, everyomne's chances of getting shot are hugely increased. For instance, in the US laws on gun ownership are much less strict than in Europe. In this sense, Dr Lewko sees statistics as the key to the regulation.

He considers a much greater risk to lie in sharing information on the internet. If would-be future abusers of 3D/4D printers have free access to certain information and data, potentially downloaded from other abusers of this technology, complete anarchy may be the end result. Potential abusers could get guidance or a complete plan for a 3D/4D printer to make not only a gun but also a bomb.

"*So if someone plans how to do a perfect gun, bomb or whatever, and we can all just downloaded and we don't need to start from the stretch... to blow something [...], so it's not only hardware but software is as problematic in this respect.*"

Obviously we cannot label technology as good or bad. The goodness or badness of a technology depends on who is using it and how it is being used. Things do not kill people, but people do.

"*I know only a few people were killed by robots, but many more were killed by other people. [laughter]. So maybe in 150 years from now, but the problem now is that people are killing each other, trying to take control of other people.*"

In this sense, Dr Lewko agrees with Dr Benedetti that it is essential to change the way people think in order to be able to use the technology without fear of abuse. They also agree that excessive regulation could hamper progress. Dr Lewko thinks that people will just do stupid things naturally, and we cannot really prevent them from doing so. The freedom we have, in this sense, is also a responsibility. We live in a free country, and this simply goes with it. The additive manufacturing of smart materials offers us a number of options, and it is up to us to choose how we use it.

"*We want freedom, but freedom also means you can do stupid things, depending on how stupid people are, we need to shut down the freedom, that's in many respects so there is no one perfect answer... because more you regulate you abuse the freedom of people. It's difficult, I don't have a solution actually... [laughter]*"

In further sections of the analysis, I am going to deal more with "mindset-shifting" issues, as they are an important part of socio-technical controversies. It is important to note that 3D/4D printing is already relatively well developed, but is the mindset[20] of society? It can take some time until society shifts their preferences to this technology, and it is also possible that society will never learn to not abuse it. What I am trying to say here is that more important than the development of a specific technology is the development of society. In this sense, another industrial revolution should be more about the mindset of people than about particular technologies.

"*Both of those things have been available for more than ten years, so not the technology side was so large last year, but what was lately a big change, or revolution or whatever… was the mindset of people, that they released that things can be 3D printed... so mindset-shifting... Technology itself didn't really evolve that much... so most of that things, which you can print out now, you could print out fifteen years ago too in a very similar quality so change was in the mindset of the people…*"

5.1.1.3 Dr Luce Cuesta

Dr Luce Cuesta is CEO of the company "L"[21] and also the organizer of the "Vienna 3D printing meetings". Similar to other experts working with additive manufacturing on a daily basis, Dr Cuesta shares their views on a couple of key points regarding the future of the technology. Dr Cuesta had not encountered the term "4D printing" before I approached him for the interview. He considers the concept of 4D printing to be just another description for 3D printing that does not use any microprocessors. The issues regarding the terminology were swiftly addressed in the interview. Just as Dr. Cuesta criticizes the name of the 4D printer, he also criticizes the notion of "programming" used by the MIT with similar arguments to those of Dr Benedetti and Dr Lewko.

His views about the benefits of additive manufacturing in society are concentrated around the implementation of additive manufacturing in industries, and regarding these his views are similar to the other scientists'. He agrees that we are dealing with another industrial revolution, and about twenty years from now, the 3D/4D printer will be a technology that every company needs. However, this will be preceded by years of prototypes and research. He notes that this new technology has not properly found its uses yet, and it is only waiting for its killer application. Such an application can refer to anything that rapidly improves old methods of production or creates something that a previous technology was not able to produce. Thus the real potential of additive manufacturing lies not only in a less time-consuming and resource-

[20] See Chapter 10.1.10, "Mindset-shifting"

[21] See web page http://www.''L''.com/en/company/company-overview/ (Accessed SSeptember 1st, 2016)

demanding method of production, but in his opinion, in a technology that allows for the creation of something that until now has not been possible, and outperforms all other existing technologies.

"*In twenty years from now in terms of prototyping and research and development. These 3D printers will be something like a must have for every company. To be used for this machine parts I think this will be in next twenty years the key application. There will be, I don't know how many applications, but there will be an application, which only can be produced by additive manufacturing and which really gives sense to work on that, and which really gives a benefit*."

Regarding regulation, Dr Cuesta also agrees with the previous experts that if someone wants to make a weapon, he does not need a 3D printer. In this, his opinion coincides with Dr Benedetti's. On one hand, regulation is not going to prevent abuse, and on the other hand, regulation could dramatically freeze the development of technology.

"*I mean, you can kill a man with a knife, and you can buy the knife in a supermarket. I think that's not really that important how it's set up. That's so many things you can do and 3D printing is only one of them... but to say, you are not allowed to print the gun or something. I don't think that this will be very useful*."

Dr Cuesta was very busy, and unfortunately, the conversation with him lasted only for a short time. However, he is a renowned scientist and businessman in the field, and his word has great weight because of the way in which he operates in his chosen area. Although he did not speak many words in the interview, he taught me a lot. He helped me to understand a couple of key points which were later confirmed by the majority of the interviewed experts. Dr Cuesta also considers this technology a groundbreaking revolution. 3D printing of smart materials may fundamentally change the current method of production and manufacturing.

It is important to pay attention to shifting mindsets because society can only take full advantage of the positive potential of a new technology by raising social understanding and awareness of it. Otherwise society may put itself at risk of landing in a state similar to how nuclear energy is assessed and understood, where any benefits and further developments from X-rays and hydrogen power plants are rejected because of nuclear accidents and atomic bombs. Dr Cuesta also confirmed that regulation is more or less impossible as well as undesirable due to the progress of scientists. Fortunately, the next expert who is also from company "L" gave me a much longer and more detailed answers.

5.1.1.4 Dr Keneth Hyams

Dr Keneth Hyams is a researcher who works in several fields of additive manufacturing, and he is one of the most world-renowned scientists in this field. He also holds a seat in the Board of European Students of Technology. Dr Hyams is a very well established scientist and his work has been published in the world's leading scientific journals. Similar to Dr Cuesta, Dr Hyams is a part of the research team of the Viennese company "L" GmbH, which cooperates with the company "S" of the University of "X". Dr Hyams is, like Dr Benedetti, originally also a polymer chemist and deals mainly with photopolymerization in additive manufacturing. His research is about the production of ceramics with the help of light. These materials already exist, he is simply trying to create them in another way.

"*So on the one hand additive manufacturing, 3D printing in a detographic manner, with using light to shape three-dimensional objects in a layer to layer manner, and here I am also responsible for material development especially with developing new kind of ceramic for additive manufacturing with not really inventing new ceramic material, because they all exist but adapting them to different manufacturing.*"

He also notes the lack of a killer application, because at the moment additive manufacturing technology is only used for the efficient production of existing materials.

Before I met Dr Hyams, he was on the phone to the company that owns the biggest printer in the world (WASP: World Advancement Saving Project). The following is an illustrative example of how important the application of this technology can be. His opinion coincides with those of the researchers I had already interviewed, which is that this technology is the future of production, or "the third industrial revolution" (Rifkin, 2011). His own words describe the printer as follows.

"*Yeah, I've just been talking to the companies who own the largest printer at the moment. It's not only just like a big house but it's almost like a factory. And they're not using plastics but they're using. It's just bricks and if you have something, which you want to produce or a material that you want to manufacture and there is an ideal solution so far, than you have to customize the process to your needs. Similar to what we did for ceramics and these guys have done for their purpose, they are building this house or sculpture or electronic equipment. There are very few limitations. But in many of these things, they are only using additive manufacturing to use additive manufacturing so it's just printing for printing's sake. You could build this company by conventional methods or sculpture by subtracting. If you're probably its artist it is sufficient to say, OK I created this by using a 3D printer but in manufacturing it may be interesting for the customer to get a product. Which was 3D printed but at the end he is only interested in the quality of the product and its price and if it's not comparable by using 3D printing, there is no sense of working with all these microprocessors or electronics. I think it's very difficult to get to this field, because its already highly sophisticated and optimized, but if it's not possible to bring and added values using 3D printing, into it there is not much sense in going to that direction but there are many fields where it's possible to get more value as benefits and that's where I see 3D printing in the future.*"

The quote above will be referred to in the hacker focus group analyses following this chapter during discussions of the designers' views on the possibilities of this technology.

Dr Hyams notes the fact that 3D/4D printing technology has not yet found its killer application because it has thus far been only used to manufacture things that are already being successfully manufactured in some other way. The emergence of of 3D/4D technology, however, provides a more efficient production technology. The way things are made (addition or subtraction) is a major breakthrough because the technology no longer acts as just a change in the method of production. Additive manufacturing overcomes the previous activities and results of production and economics.

"*I think in this case, it's going to be very, very similar to what we have done at the beginning because we developed our process around materials. So we said, okay we want to print it out, there are ceramics certain option [...] But we believe that the only right way how to do it via its lithography. And I think it's going to be for Similar smart materials that you will have to adapt, find and develop process which is suitable for those materials. It can be something like this bioprinters but it can also be different. But it certainly still has to have to some developments in this context.*"

Dr Hyams points out one crucial aspect that I was aware of from the very beginning of the study. The additive manufacturing of programmable matter, or even just smart materials, is too broad in the scope of application. This is why different people may look at smart materials and programmable matter differently depending on the field of application.

"*In biomedical applications where, for example, you can trigger the material to change its shape by temperature for example, and that's actually one of the applications or only one actually that right away come to my mind, because there are many fields where you can use these applications[…] I think each person will have its own vision depending on field they coming from.*"

Regarding the benefits of 3D/4D printers, his view is partially consistent with those of the scientists previously interviewed. Additive manufacturing methods save time and materials and also give new opportunities for production and design. These options put together allow for the precise treatment of materials for saving resources. This facility is gaining importance and the company will invest in it for various reasons, but mainly because of the savings made possible by this way of manufacturing. The design stage of development, whether creating prototypes, demo parts, new tools, or new smart materials, is not negligible. The opportunity to make things exactly with a desired shape and the precision of one nanoparticle which is highly beneficial for emerging fields in biotechnology and biomedicine.

However, in this sense, 3D/4D printing is just a business. Dr Hyams does not believe that it is going to be changed in the next ten to twenty years. According to him, it is going to take time until this technology reaches the people.

"*Complexity comes for free... so you can really design really complex shapes integrated functionalities and it does not add any costs to the parts and also customization, and that's especially for biomedical applications I think there could be [...] big market, because there is this actually a Slovakian company "S" from the University of "X" [...] Exactly this field is when, re-generative medicine, where you always need customization because every bone defect every tumor every injury is more or less unique and for these kind of applications the customization. It is essential here and additive manufacturing can have a very huge impact in my opinion*."

Dr Hyams was skeptical when he was asked about seeing the current stage of 3D/4D printing as the next industrial revolution bringing about general social benefits. While acknowledging the great benefits to industry, companies, and corporations, he expresses disbelief in the idea that the benefits of this technology will also bring benefits to ordinary people. Rather, he thinks that the technology will be held in the hands of a few influential people, as has been done countless times before. The key contributions of this technology are understood by Dr Hyams as controversial. On one hand, he talks about this technology as being revolutionary in the industry, but on the other hand, due to the functioning of the market mechanisms tied to the invention of technologies, it is going to be a long time until the benefits reach society as a whole.

"*The industrial revolution, it's not a revolution but, it can be a significant step forward its already exploited by many companies from many areas form industry but not yet everybody can benefit from it. I just talked to colleagues yesterday, and I was excited in which new areas our comparably small company goes now, when I began two and a half years ago, we've been like ok... This area is not interesting for us they're focusing on metals and we are doing ceramics, or they are doing big parts and we are you know rather doing a small structures but know we're in touch with all these companies and we are finding out that there is so many points where our technologies or interests are overlapping, and I am sure the trend is going to continue and I think it's a nice term and I heard it in so many talks and lectures an many articles this industrial revolution. It would be one if it really brings manufacture to the customers home. But I don't see it coming in the foreseeable future. [...]So that's the different areas where I see the high impact in the custom level, whether everyone can have a 3D printer I am not sure, all these companies they're still making good money right now…*"

This means that the likeliest scenario, according to Dr Hyams, is that the technology will be held in the hands of the powerful, and if it ever gets to the community, it will be through marketing mechanisms. This means that 3D/4D printers will most likely be purchased through e-shops. Perhaps there is also a reasonable scenario that 3D printers will be close to the 2D print services that we know today as "Repa Copy"[22]. Perhaps 3D printers will be in supermarkets, available to

[22] See web page http://www.repacopy.at

customers, and perhaps something like 3D/4D printer networks will emerge. In any case, Dr Hyams does not see this technology as revolutionary as scientists from the MIT see it, it and he does not think it will be accessible to ordinary people.

3D/4D printers will be a non-disruptive technology that changes everything. The point is, despite the possibilities offered by this technology and the efficiency with which it operates, it has no adequate social background yet. Again, "mindset-shifting" is essential because current manufacturing processes are so well established. While the transition from subtractive to additive manufacturing is relentless and some machines are going to be slowly abandoned and become non-existent, it will probably not harm industries and the economy in the way some prognoses show. Dr Hyams and company "L" are trying to present additive manufacturing as an effective method of production and to offer new opportunities, but a lack of general public awareness and external forces to support this trend present a problem. However, this has started to change. Dr Hyams assumes that this scenario will eventually come to pass: this method of production will be encouraged to promote Europe as a prestigious continent and an economical world leader. However, this is business, so other countries may be economically influenced by it.

"*There are many research projects funded by the European Union, which are trying to use this kind of technology trying to get production back to Europe because usually most companies are usually somewhere far east and now they're hoping in some ways that 3D printing could bring production back to people and that's something which can be possible. But I don't think that any industries really are going to suffer because of that. It might actually help to get out of the countries which stay in some parts of the world.*"

Dr Hyams imagines concrete and specific applications of the technology in space missions, where the advantages of 3D/4D coverage can be great for re-utilizing things. Whether it is a spaceship or a submarine here on earth, the fact that you can build technologies from scratch can bring real benefits. Thus this brings forward special ways of creating the necessary tools for helping the crews of both spacecraft and submarines repair devices easily, or to produce tools in places that this would otherwise be impossible. When exploring new environments, whether in the universe or in the ocean, this technology definitely has a future. The efficiency of applications and the efforts of investing in this technology in numerous fields shows a glimpse of its future potential.

Dr Hyams's standpoint on regulation correlates with the previous experts. It is difficult to determine what control should look like. Technological development brings new possibilities as well as the risk of abuse. The risk of someone choosing wrongly is a part of freedom. For instance, 3D printers can now be constructed at home for only 300 Euros, and of course, they may be used for anything, such as printing weapons.

"*That's very difficult, how this regulation might look like. To be honest that's not something I spend much time thinking about. Of course the better the technology get the more will arise the things like that because, with three hundred Euros, that will not be much a trait, but as technology becomes better, especially in the industrial scale there is a lot going on and techniques are getting better to convectional techniques and this gives people a new tool and of course it should be used for something good, but* ***of course the possibility to do something else like guns et cetera, like it's a very popular example, of course it gives like a decades ago when the internet arrived, there was this problem that you could easily look up like how to make your own bomb think this could be a similar issue but how to solve this issue that's a [...] or if should be solved I don't know, but it's going to be an issue.***"

Dr Hyams brought many fruitful things to the debate: in particular, skepticism with regard to the future of 3D/4D printers, economic objectives, and the goals mentioned above. The controversies brought up by this scientist were suitable ground to for supporting the views of the hackers. In Chapter 5.2, View of Hackers, I am going to refer back to Dr Hyams several times, as he so nicely outlined the problems of the technology and marketing goals, which were not only controversial but also provoked a great deal of discussion in the hacker focus groups.

5.1.1.5 Ing. Betsy Vogele

Ing. Betsy Vogele works in the commercial company "H", which deals with incorporating 3D printing into many interdisciplinary fields, ranging from architecture to biomedicine. Additive manufacturing technology has given him a lot of opportunities to create new designs and forms of articulation. His company, "H", has been in business for over nineteen years, and it has worked with over thirty-five types of different materials and fifteen different technologies of additive manufacturing. Their technical advances have recently allowed them to print prototypes that are 1,5 x 1,5 meters in size in under 48 hours. "H" focuses its resources and research in the field of 3D printing, but it does not engage in independent research. The company works for clientele coming from various sectors of research and manufacturing. Vogele's company has held contracts all over Europe and the United States. "H"'s main aim is to bring together researchers from various disciplines that make use of additive manufacturing, and to help them find what they need without wasting time on older research methods.

"*So we mostly work as a support for other people's research so somehow we network the process which they need. Because we have the core knowledge of additive manufacturing.*"

Ing. Vogele is the person to go to in for gaining insight on interdisciplinary research owing to the richness of his experience in it. His company has already contributed to many interesting investigations in fields from biotechnology through design to architecture and archeology. These interdisciplinary research experiences demonstrate the great opportunities

3D/4D printing brings, and allows us to see how extensive the application of this technology can be.

"*... [A]lso we work as a company and, in terms of research, we do not do that much research of our own, but we are involved in research where other partners involve us, for example we were printing 3D scaffolds for observation for growth of cells in the scale of ten microns of the elements Which were printed for example. We've also implemented into the research we did in architectural domain with the way we reconstructed the data which city were from scans from hundreds of years old and skulls than we printed the skulls from the original again which helped in the research for the archeologist and medics.*"

This particular scientist agrees with the others interviewed about 3D/4D printing heralding a third industrial revolution (Rifkin, 2011), especially in terms of energy, material, and economic efficiency. This opinion confirms that the technology has not found its killer application yet because it has so far produced only things that have been possible to produce already. The interview also brought up the problem that Dr Benedetti outlined: that of dealing with streamlining production, of letting the technology bring ecological benefits and help avoid wastage. It confirms the trend in the industry, mentioned by Dr Lewko, that since the production of any material incurs costs in terms of money, material, labor, energy, and transport, the industry is constantly pushed to be more efficient and to uphold more environmentally friendly production methods. Ing. Vogele elaborates on this with reference to a company that has started to print steel.

"*There are already many companies, if you for example had gone to the materialized world conference in 2012 in Belgium in Leuven and then you could have seen for instance the company which five years ago printed metal and already had more than fifteen machines but their point, their core knowledge was not focused that much to metal additive manufacturing but more energy efficiency and process management in that way, and using regarding quality of additive manufacturing. So in five years, they achieved energy efficiency and economic or ecological and so many levels of criteria which are supposed in Europe to be achieved in year 2025. So now they're selling their knowledge to other companies, how they can become more energy efficient and so on through these technologies.*"

However, the benefits of producing things at a lower cost have opened up a much wider field of application. The technology of 3D/4D printing gives manufacturers the ability to create anything: any tool in any place, and spare parts for everything that could be created on the spot without having to store them. Like Dr Lewko, he acknowledges the costliness of stocking spare parts. Ing. Vogele also puts much more emphasis on the cost of transport. He considers global trade where goods are transported over long distances a waste of energy and natural resources.

Ing. Vogele thinks the that current trend of shipping products from countries with cheaper labor to Europe is going to subside thanks to this technology.

"*Because not only less material is spent but there is also less labor and assembling stuff, because different assemblies can be printed and put together. Also stuff doesn't have to travel all around the world like five times until is assembled and then it goes to the other part of the world because you ordered it through the Amazon and energy is spend on the transport which is running all kinds of goods around the world. And this wouldn't need to happen because all the stuff would be done on the spot, because all you need is the data and where ever you need it so you needed here, it's printed here. So for example in automotive industry now, fifty percent, no more than fifty percent of the profit is from spare parts and servicing the spare parts and that mean that they have to have a big stock of the spare parts, which I will be no longer necessary because, it will no longer travel around the world and only that material would be spend, which is easy.*"

The benefits of technology go hand in hand with abuse andoveruse. Co-production with these two aspects creates, as we see, a very complex phenomenon. In the previous two paragraphs, I indicated how Ing. Vogele looks at the current development of this technology and how he sees its potential. For him, the most important issues are environmental concerns. Thus, the very mode of production where the elements are accurately placed in pre-designated points without unnecessary material waste reduces the waste of resources. On the other hand, the possibility offered by 3D/4D printing—that is, producing any single component or piece of technology in almost any place, avoids the need to transport and store spare parts andgoods. In this sense, Ing. Vogele, rather than calling this the future because of the economical benefits associated with the third industrial revolution (Rifkin, 2011), or as named by Dr Benedetti, the revolution for the human being, talks about how the technology might turn into an ecological revolution._This term is used primarily in the_context parallel to 2D printing, which was also outlined by Dr Benedetti. Thus we need society to understand and undergo development before the effective use of new technologies can happen, and to prevent the overuse of this new technology.

In the context of the parallels, Ing. Vogele fears an initial waste of resources, as was the case with 2D printing. In this sense, he is entirely consistent with Dr Benedetti. Let us just give this another look.

"*It's more energy efficient. It's like... It can really help because this state which we have in the world now is also because of overusing or abusing technological possibilities for stupid production. Also, for example, there is this danger with 3D printing like ok now we can do whatever, so of course people will also print stupid stuff.*"

Ing. Vogele considers the MIT's stance as just a "buzzword", as Dr Benedetti already called it. Ing. Vogele also had never heard the term "4D printing" before I contacted him. Ing.

Vogele's assumes that, after the arrival of a killer application, the name of the technology in the industry is going to be made more official. Ing. Vogele also assumes, like the other experts, that this term is misleading. However, it fulfills its purpose: it frames this technology to the general public.

"*So maybe something similar will happen with the name 4D printing that one day it might become more precise or exact or to the point. But as a working prototype is cool, because it allows to idolize and conceptualize the next step.*"

Ing. Vogele wanted to say that the framing and the naming of the technology ought to arise from its practical use and application. The name "4D printer" is relevant to the arguments that researchers from the MIT have provided so far. It creates an idea of what the technology can do and what the possibilities are. In this sense, he partly agrees with the researchers from the MIT that we are discussing a material that obeys natural laws and is not really "programming" by itself.

"*I think one part of this is evolution of the quality level of material definition what a printers can achieve because basically with this so called "4D printing" which I would argue a little bit but for the sake of argument it's ok. Because all these dimensions are of different kinds, but anyway, what is interesting is another thing which is the scale on which it operates, but what I wanted to say is, before it was not possible because the material definition and the grandness of the printed material would not allow to sort to say to program or embed this properties of self assembling of motives in to the matter. Now with like for example stratosyses conex machine you can do the digital materials or gradience materials which change the properties in to one print so it can be flexible and transparent and colored and rigid in one print. This allows material grandniece, which reacts than for example with water, conditions of humidity or magnetic conditions or movement or kinetic energy. It's like a natural evolution of the technology itself. It only reached certain level of the definition of the technology itself it only reached a certain level of the definition , that now it can do this.*"

Let us get now to the framing of the future development of 3D/4D printing. All of the scientists interviewed agree that the technology is going to become more and more affordable in the future. However, it is not going to become an ordinary part of households because a hobby will remain a hobby. The lack of accessibility regarding knowledge, equipment, and materials will not allow ordinary people to own a 4D printer. This technology will remain most beneficial for the commercial sector, while a trend may possibly evolve in companies needing to own a 3D/4D printer. Although Ing. Vogele looks at the issue of analogy similarly to the other interviewed experts, he is far less skeptical of the future of 3D/4D printers as a standard part of normal households. He assumes that after the expansion of 3D/4D printing in the commercial sector, the next step will be the cheapening of the concrete printers, and it will become perfectly normal to have this kind of printer at home. This does not necessarily mean people will be able to print whatever they wish. As in today's world, while people may have a low-priced printer at home, capable of standard A4 printing if they want to print a high-resolution poster they have to go to a specialist service provider. We can we expect similar developments with printers that are going to be capable of more than just 2D printing. It might become commonplace to have a 3D printer at home while it might still be largely inefficient and uneconomical to have a 4D printer. People will rather opt for a company that will produce desired goods for them.

"*For the 3D printing, we still don't know what the killer app is, we don't know, we are waiting for it. And then other aspect is evolution, we can compare the evolution of 2D printing. Imagine twenty years ago, a pin printer could cost a quarter of million, had eight pins, was noisy, was slow and tool a minute to print a page and it cost the same as three cars. But nowadays, everyone can have a very cheap, for tens of <euros printer A4 format but still if you need to do a big drawings for projects, or print photos or do anything like that, you go to the specialized spot, where they have plotters, where they have, because still, this is going to be expensive and industry will keep it that way, that of course some better standard that is now will be massively adapted but still the high end and from certain level or from certain level there will be still these industry specialists and 3D printer supplies will have what to do and lot of work.*"

We are again met with the problem of missing a killer application for 4D printing to experience such exposure. We do not know what the killer application for the 3D/4D printing is yet or what it should be, but we know that it will certainly help to promote this technology and will change a lot in the field. Meanwhile people, due to the lack of a killer application, do not know how to use the technology efficiently. People fail to properly exploit its potential, and so printed products end up among junk in garages. Most of the experts discussed the operating performance issues potential users will need to deal with. Another problem is that lay people often do not have a clue as to how to use this technology. Ing. Vogele raises this issue in the shape of a question for which he provides a comprehensive answer.

"*It's not on a level of industrial deposition modeling, which is thirty years of research and developments and refine process on all levels, so yeah, people bougth hundreds of thousands of this like make a boats and whatever but what they been printing? There is this statistical research, which shows that these 3D printers stand at home or at garage. Ok maybe these people been printing first two months but afterwards, they didn't know what to print, but that doesn't says that phenomena will not occur in the future and people will not learn how to use it, because it's like with killer app for computers, because it was like what are the computers for. Until there was no table processor like nowadays is excel for instance. After such a thing was put to practice, then suddenly everyone wanted a computer, economists, scientists, meteorologist. Because that was the killer app*."

This technology has demonstrated a suitability for a number of applications, but as all the interviewed experts agree, the true potential for additive manufacturing has not yet been revealed. Because there is no killer application yet, it is difficult to determine how the technology will develop in the future.

This can lead to the potential of this technology being exploited in terms of producing more precise weapons. The technology also offers up the possibility of developing new materials and shapes, which can support the development of mankind. In either case, the benefits of this technology can enhance many things from productive forces as in the arts to destructive forces in wars. Of course, a technology can also become destructive through its creative potential and the creation of secondary waste. This is waste that arises in the production or the end results as something surplus, and quickly loses its applicability and thus becomes waste.

"*There are companies like for example the solid concepts, which was bought now by 3D systems, which is a company which is making also a guns but for thirty years and expertise in other techniques of producing guns and of course they bought this machines and produced an remake of an old revolver but tuned from inside from possibilities, which additive manufacturing and metals allow so it was more silent when it shot it et and then they sold it as a special edition of the gun you know. [...]*
So always there will be stupid people, who will grab the inventions for their own twisted ideas. What we can do is do our positive stuff and try to make more of it."

From a dialectical perspective regarding the benefits of this technology—looking at it through the aforementioned lenses and thinking about all the aspects of this technology mentioned above—regulation gives us the control of another, deeper sense of risks that need to be managed. We can see four key aspects that are the opposite of each other in using this technology.

The first aspect is that of retrofitting older products and enhancing the efficiency of production in relation to the possibilities of this technology with the goal of producing new materials and shapes. The second aspect lies in the purpose of using this technology for productive goals, such as the production of safer aircraft materials or in relation to the use of this technology for destructive goals, such as the production of weapons. The third aspect is a quantitative measure of this technology: whether in companies or in households, the technology should be used only for necessary things. The possibility exists that people will print things just because they can and because it is cheap. The fourth aspect relates to this technology and the ecological-economic consequences of its use. On one hand, there are economic benefits to the use of this technology: greater independence in access to necessary parts or materials, and no longer sustaining pointless spending costs in warehousing and logistics. On the other hand, there are environmental consequences resulting from the use of this technology, possibly saving resources in terms of the materials required for production, as well as in terms of energy consumed during transport and crafting. The ecological consequences include the possibility of excess production—which ends up in waste—or if the products are recyclable, recycling needing again to consume energy.

It is difficult to determine how the regulation should look like. The development of this technology should be promoted because of possible new opportunities and effective inventions. Through this, we have also come to the question of plagiarism and copyright. A random person can download the sketch of a modern car engine and print it at home. By doing this, he or she is infringing on copyright. Another thing is to make sure to maximize the productive side and to minimize the destructive side of the technology.

"*Yeah, there are already certain legal issues which deals with the printing of guns. But then also in choosing an intellectual property because you have a printer in the sufficient quality and then you are going to print for example a new carbon engine. Carbon engine was design for example by Ferrari. Also there is a question for authorship issues in the legal sense, because if people will produce digital projects, than it can be easily stolen and abused, so there is also this question of coping and what can be copied, under what circumstances and now there are starting to exist companies which are only specializing in legal questions of this field and exposing of what, in the sense they're also looking into new kind of work, they are lawyers basically but these questions are actual and they will pop up more and more because there will be always some stupid people who will try something, because it can be done and in their thinking is a question, why it can't be done because and so on.*"

It is important to support the understanding of technology through frames like the "inscription" of technological objects (Akrich, 1992), which means that scientists have to inscribe their visions into technology during its construction and thus report them to the user. Science should not be held back, but it should be encouraged to develop productive inventions and also establish a framework for users to engage with.

"*One thing is that we scientists have to regulate, because people don't know how to regulate themselves. Because if people would be acting at least with the common sense and heart, then all these regulations would be not necessary, unfortunately that's not a case and people act like selfish animals in most cases so of course you can abuse the technology also 3D printing and this case of a guy, who was trying to print a 3D gun and then Stratasay came and took his printer, which he had on lease because it was more like a public story.*"

It is essential to note that any technology can be abused, and we must develop social values that will prevent the abuse of technology. We cannot say that all companies will develop weapons and destroy the earth because of this technology. There certainly will, however, be companies that will use the advantages of this technology in the creation of weapons.

"*There are companies, where people have kind of ethical stands and character and they don't do this, for example materials, which I seen as one of the most visionary companies in additive manufacturing* *in the world, they never take military jobs, even if it would pay a millions, basically they will not take it. They are making a better world through 3D printing not worst world and that's what I also agree with.*"

The observations of Ing. Vogele were inspiring and added to the well-developed concepts that I have previously mentioned. I also tried to incorporate the views of the other interviewed experts throughout the explanation so that the reader could better make sense of the delicate context and the differences in their views. When elaborating on the interview of Ing. Vogele, I tried to outline the context and complexity of his research to make it clear how complex concepts arise. As can be seen, the opinions of scientists, no matter what field of additive manufacturing they come from, are consistent and mutually reinforcing. Ing. Vogele had many insights on technology, but he did not have ideas that had not been expressed by the other experts. The consensus among scientists assured me that I had reached a theoretical sampling. The next interviewed scientist had some good observations, and these will also confirm the earlier standpoints of the other experts.

5.1.1.6 Dr Haywood Sonquist

Dr Haywood Sonquist is a professor at the Technical University of "X" and CEO of the company "S". He is one of the most respected biomedical engineers in the world as well as one of the most prominent developers of using additive manufacturing in this field.

His current topic of research has already been in progress for four years and focuses on implantology[23] and 3D printing in the field of pathology. While biotechnology and regenerative medicine as topics of discussion have already been discussed by some of the other researchers such as Dr Benedetti who worked on developing printing implants for complicated bone fractures, none of the other experts deal with biomedicine, biochemical engineering, and 3D printing like Dr Sonquist does.

Dr Sonquist emphasizes the need for technological literacy when dealing with 3D printing. This has already been mentioned several times by other interviewed experts and can be considered an in-script in certain way. I am going to elaborate and connect the notion of in-script and 3D/4D printing in the next chapter: 5.1.2.3, Inscribing Additive Manufacturing/Philosophy of Engineering Technology. In Dr Sonquist's view, 3D printing today is not yet a very firmly established technology in industrial and medical use. He notes that in order for one to be able to operate such equipment, it is necessary not only master 3D printing, but to also be an expert in the field in which this is to be used. The demands on the user were expressed in the interview by Dr Sonquist several times through discussions on the various issues of 3D/4D printing.

"*You have to have the skills not only in the field like when you the medical applications, that means medical skills, but you have to know also a lot of things from the methodology from the using of the printer, from the material's point of view, from the accessories you have to work with together with the printer and many other things to achieve successful jobs with the 3D printer. Also, this time you have to care when you're trying to use 3D printing and use your full time you want to be good on it. Also in short time we'll get some plug and play printers from the developers and producers and it might be much easier to work with 3D printers.*"

As Dr Lewko noted, the logistics required by an industry demand a judicious choice of manufacturing process. Dr Sonquist also touched on this topic. Dr Sonquist noted that although it may be useful in some cases, additive manufacturing is not yet advanced enough to replace old methods of manufacturing, especially as some of them are still less expensive. This is true especially with regard to mass production. While injection molding is currently much more effective than 3D printing, the development of this technology could change this in the future. This may involve a larger printer that will be able to print multiple pieces simultaneously, for

[23] A form of regenerative medicine.

instance. After this development, the technology of 3D/4D printing could realistically push aside the current practices of injection molding in the industry. Dr Sonquist's attitude in this case is similar to Dr Lewko's opinion, and I will engage in a deeper analysis of the differences and similarities later.

"*At this moment is efficient but you have to again look at this problem from different point of views. For instance you have plastic injection molding, yes, this is always less expensive than 3D printing and you can do series productions by inject molding or this similar type of technologies but I see that there is also an effort of people who develop this kind of machines to create a big machines with a possibility to produce serious production many parts at once, so I see that when this will be done I think that many of 3D printers will replace classical molding machines in industry, but it's only one point of view.*"

According to Dr Sonquist, 4D printing and smart materials generally have great potential. This lies in their ability to self-replicate. This aspect has already been brought up many times by the interviewed experts, but Dr Sonquist goes further by demonstrating some of the major fundamental applications. The advantages range from aircrafts to regenerative medicine, and to technologies as small as one nanoparticle. This applies even to technological objects used daily, such as phones. Dr Sonquist sees great potential in having a phone or a computer which after breaking or scratching can "heal" itself. It is a great idea, especially for young teenagers, but also for professionals who constantly fear for their data.

"*This time you can see that for instance that in the last CES 2015 I Las Vegas was introduced a cell phone which can self repair of course there is a big potential, because as people are carrying the notebooks or cell phone ,they want them to have always new. This is only one field but it's a big potential and I still think that there should be a large research done in respect to have a good results in this field but of course the potential is very big because as people are creating, people are also damaging the stuff and a when it comes to the medicine, that's where I see the big advantage for the future and this will be a revolution when human body will be able to repair itself.*"

Like other interviewed experts, Dr Sonquist also is very skeptical about the terminology used by the MIT regarding the printing of smart materials and the name "4D printing". He agrees with Dr Benedetti's assessment of the title. The name of this new technology is mainly a marketing strategy aimed at popularizing the technology. The criticism about selecting such a name is based on the idea that the name does not correspond completely to what the technology is doing in reality and as such is unwarranted, and it might also be misleading for a lot of people.

"*The 4D printing I heard about, because now it really actual to speak about the 4D, 5D, 6D [laughter] and all these, let's say trends but in 3D printing I've heard about the issue of time but I am not working in this parameter in this moment. Of course this parameter is working by itself, because* *time is something, which is flowing and we are not watching it, watching this parameter but of course it's an issue in the 3D printing.*"

Regarding perspectives on future developments, Dr Sonquist's opinion also more or less coincides with the other scientists. He considers additive manufacturing to possibly constitute a third industrial revolution because of its great potential in the industry, construction, and other sectors. He indirectly points out the lack of a killer application. 3D printing has so far been mainly used for replacing preexisting production methods in order to produce things that are already being produced, but he believes that we can expect that with time, additive manufacturing will begin to produce entirely new things. Unlike the other scientists, Dr Sonquist raised a major technical problem of 4D printing: that of repeatability. The printers are unable to reproduce a completely identical product multiple times. However, these and other problems can be remedied over time, and he firmly believes they will be.

"*Now trends are in miniaturization, but in opposite to other fields there is an interesting way and it's in creating a big printers also probably there will be revolution in building industry as well, houses will be able to be printed out by 3D printers probably and big things, which are around us. From another point of view the miniaturization and the precision will be an issue but now the biggest problem with 3D printing is repeatability, hopefully this will be solved and we will be able to get the same parts after each printing and I see that there is a big space in developing a new materials and this will be crucial for developing of 3D printing because now people are trying to use different types of materials like foods, like different types of metals, wood, plastics and so on. And for the future a see that composites will be a trend or using completely new materials for 3D printing.*"

In terms of the use and the engineering of this technology, Dr Sonquist sees some large gaps that future developments may change. The gaps are mainly due to the lack of repeatability and the impracticability of these devices due to their size and slow work speed. Dr Sonquist also brought up some very important questions to which I will return with the hackers. What are the boundaries of using this technology? Additive manufacturing is quickly becoming current trend, but Dr Sonquist warns against people using it in industries where there already exist better ways of producing goods.

"*I hope that people will be able to get the answer, where is the range of 3D printing and where is the range for other technologies because people are still forcing to use 3D printing, but in the particular cases it's better to use other methods and this will be very important to know where is good to use 3D printing, where the other methods its better and for the future also I see that handcraft and handmade product will be always the most valuable thing we can get because it was always like that and I see that human hands and human craft will on the top, like now you have Rolls Royce and other cars which are made by human hands and they belong to the top of the cars I also see in the other industries the craft handmade is and will be top what you can get.*"

Dr Sonquist, as well as other experts, do not think that this technology will become a household item. His opinion is quite close to Dr. Lewko's: a hobby will stay a hobby because of the complexity of the technology. Dr Sonquist notes that this technology will be used for challenging production efforts, rather than as a "children's toy" or a repair machine in households. The point is that although current trends suggest that 3D printers are going to appear more frequently in households in the future, in his opinion, these exceptions will disappear over time. Thus the trend is thought to be just a temporary affair.

"*Probably from my point of view, people will have 3D printers at home but they will use it mostly as a toy not as a tool for creating some broken plastic things or some other things, so they will use it mostly as a toys to see how it works for the children to create some things as a fun but not from my point of view as a tools for replacing some damaged or broken things to create a doors handles or I don't know, whatever, because people are always, people have always less and less time and for this you'll need a certain time to learn to know how to work with the printer to work with it also I think that people will use it as a toy in free time but not as a tool. This is just a revolution in this moment but I think this joy or enjoyment will go down in the future.*"

We come face to face again and again with the question of how the technology of 3D/4D printing should be regulated in the future. The lay person's difficulties in being able to operate a 3D/4D printer can be seen in the context of the regulation as inscription, since not everyone can easily and instantly print a gun at home. It would be easier for potential abusers to make it by more accessible production methods in the garage. However, even if the hurdles were not so many for a lay person to operate the technology, Dr Sonquist is not worried about it being abused in such ways.

"*This is just a revolution and people are trying to do whatever they see and want and I think that that's only at the beginning, maybe the problem will be when 3D printing of metal will be too easy, as I said when it will be just plug and play, than that could be a danger because people can print out whatever they want, now it needs lot of skills to work with metal printing but I see that there is a big gap regarding this but that's only on the beginning. For the future I don't see that it will be the revolution, that it will be abused by the people*."

Dr Sonquist, as well as other experts, mentioned in their interviews that they think regulation is neither possible nor desirable. The most important aspect of this notion is not just that the regulation of 3D/4D printing could prevent further research of this technology, but that regulation could also prevent its use in areas where it is not really needed. It is difficult to regulate and to prevent the misuse of technology while at the same time not prohibiting the search for its use and exploration.

"I don't know whether this restriction will not restrict as well the normal 3D production, because you cannot separate the producing of guns and the other things by 3D printer and it will be not so easy and from my point of view as I said, you have also subtractive machines and there you have to do also some restrictions regarding this because 3D printing I think is the same you are just adding the material at this moment I don't see the need for new laws restrictions."

5.1.2 Evaluation and Connection to Concepts (Mindset-Shifting, Inscription, Critique of Term Programmable/Third Industrial Revolution , Engineering Technology, Regulation/De-Scripting and Black Boxes)

That was our last scientist, and by the differences and similarities in their views we can see how their attitudes depend on their activities. For each of the scientists, I wanted to briefly and concisely describe their roles in my investigation. Targeting research was very significant because, as we have seen, although they all deal with 3D/4D printing, their focuses vary greatly. It is also important to note that the areas of expertise of these individuals overlapped with each other, which can be helpful for looking for the widest range of possible applications for this technology. Every scientist outlined an idea of how we perceive the application of this technology today. We could see that even if the technology is relatively new, it is quickly penetrating the daily practices of designers, architects, doctors, engineers, and many others. Every scientist has said what they thought drove the statements made by researchers from the MIT. We could see different attitudes towards the name and overall framing of this technology. Every scientist spoke of their ideas about the future of this technology. We could observe different opinions on whether this technology will be a part of the standard household, though only one interviewee had an opinion on the future of the technology industry.

Now, I will begin a deeper interpretation of the interviewes. I am going to elaborate on their similarities and differences between the opinions and attitudes of the experts. The biggest controversies to be addressed are terminology, mindset-shifting, the extent to which this technology might comprise the third industrial revolution, and how the lack of a killer application shapes the technology, while at the same time bearing in mind how the invention of a killer application could boost the market and the production of 3D/4D printers. These controversies are mainly related to how the technology is used today. The focus will be on the future development of this technology through people who are at the forefront of its development in Austria, and who are in-scripting the technology, developing a range of possible regulation goals, and the extent to which all of this is possible and desirable from the perspective of these people. The main emphasis will be on the possibilities of misusing the technology.

I am also going to also sketch the main interfaces of orientation from the perspective of experts. I managed to interview an architect, a biomedical engineer, material designers, and two polymer chemists. These ndividuals had very different foci. The applications of this technology aretoo broad to be researched just in one field or subfield. I started with a few fundamental aspects of 3D/4D printing, the essence of which lies in the more efficient and less demanding manufacturing of materials and tools. Thus 3D/4D printing allows for a chance to eliminate unnecessary transport and time when someone wants to replace a damaged component. In addition to reducing dependence on suppliers, it decreases the cost of the transport and storage of spare parts. The possibility to produce materials in new ways offers a cheaper solution for producing multifunctional materials, but as underlined by experts, a suitable method of production must be carefully chosen, since not all the 3D/4D printing methods are more efficient than existing production methods. However, additive manufacturing as an evolutionary and improved method of manufacturing offers the possibility for the creation of new shapes, which in turn offers new opportunities—not only in the production of more precise and more efficient products, but also new shapes. The possibility of producing new shapes plays a critical role in the production of prototypes today.

5.1.2.1 The Use of 4D Printing and Mindset-Shifting

As was indicated in the previous paragraph, the technology of 3D/4D printing offers too wide a range of possibilities for people to grasp its true scope. Society still does not know how this technology can be utilized. Therefore it is necessary to implement the advice of experts who deal with the technology, as well as that of constructivist experts (Bogner, 2009; Littig, 2013), who have specific functions in the development of the technology of 3D/4D printing in the Austrian socio-technical context. Such experts belong to a small group of people who firmly believe that this technology has the power to move humanity towards a better tomorrow. In the words of Carl Mitcham's (1994) philosophy of engineering technology, these are people who believe in humanity in the materialization of technology. That may be the reason why their attitudes in the interviews did not reflect any dystopian concerns, or worries that the new technology could introduce a great risk of abuse and destruction.

Regardless of this faith in humanity, the experts' outlooks were very broad, and their perspectives confirmed their positions as experts in their given sectors in additive manufacturing. In the section describing the attitudes of the experts, I mentioned their relationships with other companies and participation in conferences. They saw these forms of interaction as providing them with a very useful way of connecting with colleagues from all over the world, further proving the multidisciplinary range of additive manufacturing.

Dr Hyams had been engaged with the company that owns the largest 3D printer in the world just a few minutes before our interview, and he spoke about the broad applications of the technology. For example, the use of this technology for the production of electronics is problematic and also sometimes wasteful.

Dr Hyams: "*But in many of these things, they are only using additive manufacturing to use additive manufacturing so it's just printing for printing's sake. You could build this company by conventional methods or sculpture by subtracting. If you're probably its artist Sufficient to say, OK I created this by using a 3D printer but in manufacturing it may be interesting for the customer to get a product, which was 3D printed but at the end he is only interest in the quality of the product and its price and if it's not comparable by using 3D printing, there is no sense of doing with all these microprocessors or electronics.*"

This statement outlines the problem of the missing killer application for 3D/4D printers. The use of additive manufacturing has only recently started becoming fashionable, and the technology is not yet used to its true potential. The large amount of fields in which the additive method is making a great impact surely adds value to the technology. However, in order to make use of its potential, people's mindsets must change.

It may sound a bit paradoxical that technological experts with such a wide range of foci have not found a killer application yet. However, it is important to remember that the possibilities offered thus far by this technology are not negligible by any means.

One of the differences between 3D and 4D printing is accuracy. In 3D printing, the accuracy is as precise as one nanometer. In 4D printing, because more biological rules are put to use, the accuracy is not as high, and mass production could create problems. Nevertheless, the number of areas where it can find a unique application is growing exponentially. With its multi-functionality, we can use this technology to reduce costs and, consequently, to create a greener economy. As Ing. Vogele pointed out, the automotive industry derives 50% of its profits from storage, and transportation consumes energy every day. An example of this is transporting parts originating from China around the world. This aspect can be overcame with 3D/4D printing, owing to the possibility of being able to produce equipment on the spot and not having to store spare parts.

In this sense, the killer application of additive manufacturing technology is its ability to produce spare parts. However, before this can be made use of, there is a need to change how the market and economy works, and this change needs to come from the "mindset" of people.

Ing. Vogele: "*There are already many companies, if you for example went to materialized world conference in 2012 in Belgium in Leuven and then you could see for instance the company where, which five years ago they printed metal and they already had more than fifteen machines but their point, their core knowledge was not that much metal focused additive manufacturing but more* *energy efficiency and process management in that way, regarding and using qualities of additive manufacturing. So in five years, they achieved energy efficiency and economic or ecological and so many levels of criteria which are supposed in Europe to be achieved in the year 2025. So now they're selling their knowledge to other companies, how they can become more energy efficient and so on through these technologies.*"

Again, it should be noted that the extent to which this technology can be truly beneficial needs to be evaluated and contrasted with how fashionable it is seen as. The final usefulness of this technology is not about how something is made, but what the final quality of the product is like.

This technology brings up a lot of controversy, and to understand the technology, it is necessary to understand the circumstances of its creation. The "know-how" is obviously beneficial for the creators of the technology, but it may also encourage an irrational standard of production where methods other than 3D printing may be more effective. The origin of 4D printing is not what we may think at first sight—rather, it came about through efforts of bringing production possibilities to places where production would not be otherwise possible.

Dr Hyams: "*Yeah I mean, this was a really big in the media, this first 3D printer, I don't know if they done it eventually or getting one to ISS space station for producing spare parts. I mean this can be a root if this technology […] I mean like a desktop systems that really also gives feel to the parts, which actually can be used so sufficient material quality, sufficient resolution. In this case there can be of course some applications. I think this is nice example to bring first 3D printer to space or into to submarine underwater, I don't know there are loads of applications for that. I've just read about that, you probably know, this Space X company from the founder of Paypal and later on Tesla and his goal is this "Space X company" ITLA, like NASA or ISA, he's starting his own space program and his goal is to fly person to Mars and especially for a very optimistic visionary ideas like that this 3D printer on this spaceship could of course be a very interesting thing or something, which might be even necessary.*"

This is an important aspect of this technology, as the possibilities offered by its capacities mean that it may eventually be exploited in extreme locations. That is an abstract and extreme case, though it portrays the kinds of new opportunities that the technology of 3D/4D printing offers. In this regard, inhospitable places are also going to also create a killer application for this technology, based on what the subtractive method could not produce. As an example, we can come back to the "replicator" from Star Trek, which at first only served food and later evolved into a multi material production device.

Here we see that, despite some of the limitations associated with 3D/4D technology, it can be used for completely new opportunities.

Dr Sonquist: "*From the other point of view of miniaturization, the precision will be an issue but now the biggest problem with 3D printing is repeatability, hopefully this will be solved and we will be able* *to get the same parts after each printing and I see that there is a big space in developing a new materials and this will be crucial for developing of 3D printing because now people are trying to use different types of materials like foods, like different types of metals, woods, plastics and so on. And for the future a sea that composites will be a trend or using completely new materials for 3D printing.*"

The current trends of technology go beyond just technology, and the 3d/4D printing venture is under pressure to adapt additive manufacturing for electronics manufacturing. This kind of development is not only taking place in the field of electronics. Attempts vary from printing food to the development of a new material technology that can bring well-deserved "fame" for 3D/4D printing in the eyes of society. The "4D printing" name issue which has been mentioned several times could be resolved so that the final name reflects the technology more accurately.

Miniaturization and increasing demands on accuracy and repeatability, with pressure on the overall quality of the product, are not the only barriers that prevent this technology from being fully developed. The main problem is mindset-shifting. Ordinary 3D printers offer us the opportunity to create entirely new shapes, but at the same time people are most likely to only produce already existing shapes. This is because most people cannot imagine how something might look like in terms of new shapes if they have not seen them before. Another complication is that the concept of a 4D printer is difficult to explain even to an expert, much less a lay person. The problem lies in it being a "transformational" technology (Rothenberg, 1995). People tend to imagine technologies on the basis of what is already well known to them. However, because 4D printing combines so many aspects into one technology, no one partial comparison will be correct, and thus there is a need for mindset-shifting. I think this phenomenon is explained very well by Dr Lewko in the following quote:

"*Both of those things have been available for more than ten years, so not the technology side was so large last year, but **what was lately a big change, or revolution or whatever […] was the mindset of people, that they released that things can be 3D printed [...] so mindset-shifting** […] Technology itself didn't really evolve that much […] so most of that things, which you can print out now, you could print out fifteen years ago too in a very similar quality so **change was in the mindset of the people**…*"

In the view of participants, the possibilities and advantages this technology offers are already a bigger deal than we can imagine. Humanity must still go through a certain evolution to be able to fully understand the potential of this technology and its use.

Scientists and lay people associate 3D printing with injection molding, and 4D printing as a form of 3D printing that behaves like a living organism, which is largely misleading. Unless these assumptions go change, the use of this technology will also change.

The absence of "mindset-shifting" may cause the additive method of production not finding its application in replacing traditional machines in manufacturing. The reason for this is that traditional methods of production are, for many companies, well established and production using new techniques is risky and may look too expensive. This idea was well expressed by Dr Hyams:

"*I think 3D printing is not a technology like many people say it's a disruptive technology and will change everything […] from production to the way we think, also it will have an impact especially in a way we think, but I always say when I am attending conferences that this technology does not aim to be the substitute for the existing technologies because some methods are well established.*"

But this may change over time as outdated methods of production will be phased out.

Subtractive manufacturing is supported by the European Union in an effort to bring production back to Europe from other corners of the world. However, at this stage we should remain skeptical of this possibility, as the mindset shift in society is a process that usually does not take place quickly or clearly.

"Mindset-shifting" can also cause a number of problems. Although this technology provides a method that produces less waste in the production itself, there is a high risk of waste arising from excessive production. The parallel comparison with 2D printing, as noted by Dr Benedetti and Dr Vogele offers a great way of looking at this potential. We can influence the mindset shift and overcome environmental issues by wisely using more affordable and accessible methods of production. We can combine this with the gap between human needs and understanding the consequences of any production through notions of environmental pollution.

Encouraging the mindset shift can be performed by familiarizing people with the potential consequences of 3D/4D printing on the environment and the potential shortage of resources. It is necessary to anticipate the consequences of our actions.

Dr Benedetti: "*If additive manufacturing will be cheap and own by many people at home**, then we can expect also loads of wasted material and printed nonsense and this leads us to the point that nature will not be saved much in this sense.*** *And that's why we need to think, before 3D printers will be part of the households, if they will, but that's another question, how can we regulate printing of unnecessary things.*"

I am going to elaborate on issue of regulation a bit later in this chapter. Now I want to underline how getting sympathy towards the environment or at least avoiding callousness towards the environment is an important part of shifting the mindset. The parallel with 2D printing shows us that people must somehow learn to be environmentally friendly and thus go through an ecological revolution. However, I think that ignorance is not an excuse, and it is necessary to raise awareness in the population so that society will be prepared for the arrival of such a technology (Norhaus and Shellenberger, 2012).

4D printing is not just confined to additive manufacturing, and because it brings together 3D printing and smart materials, it reinforces the mindset shift. This is the industry's fastest growing technology since the establishment of nanotechnology after World War II. The term "programmable" is often associated with nanotechnology. However, it is also the most controversial of the terms in play, and the following sections will elaborate more on this.

5.1.2.2 Critique of the Terminology by Experts

"Mindset-shifting" is often given rise to due misunderstandings which occur in the process of the conceptualization of technologies. In the upcoming chapter I will elaborate on what linguistic controversies the scientists perceive regarding the term "4D printing" after describing the engineering philosophy that scientists have created for 4D printing technology, and the "in-scripting" which follows this process, I am going to elaborate on how effective this in-script can be and how this technology can be misused.

Skylar Tibbits (2013) introduced the additive manufacturing of smart materials originally under the term "4D printing". It should be noted that the given name offers an introductory frame. It is the name with which this technology is presented to the society. The introduction of a technology through mass media is the main input for the development of socio-technical ideas, since it allows people to become familiar with the technology even before they can experience it in real life. A secondary and not at all insignificant factor arises from the way people use technology. The possible uses of technology in practice are again a major source of inspiration and input for scientists' inventions. Brown, Rip, and van Lente (2003) note the need to anticipate and prevent the misleading inscription and prescription of technology, especially in the case of fast-changing technologies. The combination of 3D printing and smart materials gives the concept and term "programmable" a whole new meaning. The idea that one can draw something on the computer and thus determine how it will self-assemble is very controversial. Could this idea just be the kind of a misconception of the technology that Brown, Rip and van Lente (2003) warned us about?

The future is uncertain and difficult to predict. The more we try, the more we realize how many different factors exist, each of which may influence future development. When attempting to influence the social reality, an important factor of the process is how social order is interpreted by different individuals. While there exists a vast range of different interpretations and a diversity of views, scientific studies cannot account for this. They therefore hold paradigms steady. However, what happens if the experts do not agree? 3D/4D printing is a technology that experts cannot agree on from the outset. I have mentioned several times how the title of the technology does not enjoy a consensus, and how Austrian scientists disagree with name chosen by the experts from the MIT. Ing. Vogele provided an interesting statement, as addressed in Chapter 10.3 Conceptualization by Coding,[24] in which he describes how 3D printers in the beginning had about seven different names, but pressure from industry and trade forced the stabilization of one name only. The same can be expected for 4D printers.

Care must be taken to call things by convenient names so that the name does not lead to distorted visions. According to Jasanoff (2009), local sociotechnical imaginaries, as well as scientific, political, and corporate objectives, are affected by how technologies are represented by mass media. It has to be noted that the promotional videos of the MIT are aimed at defending their corporate interests of the American society. We see that such promotional tactics do not hold water in the eyes of the Austrian experts and hackers who are much more skeptical about new technologies than the targeted viewers of the promotional videos from the MIT self-assembly lab. This raises the question of how the framing of this technology should be designed in the Austrian socio-technical context. This end result will depend on how the technology is framed today, and on what economic forces are going to influence its future development. To understand the linguistic controversy of the concept "programmable", I will show how significant the consequences of incorrect or inaccurate terminology can be. Dr Benedetti describes name issue of the term "programmable" as follows:

"*It's very important what language we are using. If we would take the term as programming, where you code something in the computer and then you expect it to evolve exactly as you pre-programmed. 4D printing it is programming to the certain level but also to the certain level it's not. [...]This means that it's both but also none of them, because in the programming, if we take for granted that this term in this relation means that we use computer, we are dealing with engineering where results are usually not so exciting and progressive in additive manufacturing at the moment [...] In the issue of 4D printing, we can observe both of these, engineering and biology go hand in hand to create something absolutely new.*"

In this statement, it can be seen how terminology can vary for different researchers. In other words, something for which one set of experts seem to have a clear definition may be controversial to other experts. We have not even included lay people, whose opinions about terminology differ as well. Calling the same thing by different names, as well as calling different things by the same name something different, is generally an issue in society. It may also be that for many things, expressions can be misleading. All the interviewed scientists agreed that the terms used by scientists from the MIT are misleading, and that their terminology does not adequately describe what this technology can and does do.

Before we name anything or start thinking about why something is named what it is, let us think about why it is essential to have a good name? Names allow people to imagine a

[24] See Chapter 10.3, Conceptualization by Coding

technology in a certain way. People hear a name and start anticipating something about the technology on the basis of how it sounds, what they heard, and what they have experienced with the particular technology. This framing affects what people expect from a particular subject and how they imagine the use of a particular technology. The name of any such technology is a serious matter. We can assume that this is the same for 3D printers. A similar pragmatism in choosing a name can be detected in the choice of the scientists at the MIT when they called "4D printing" by this name. The experts interviewed in this project, in principle, agreed that this name is inaccurate, misleading, and overly ideological. It is considered a buzzword designed to acquire attention. The core of the controversy lies in the fact that this technology is not as new as the MIT says. They just shifted their focus to smart materials applicable for 3D printing.

I can see the argument and understand why they wanted to showcase their unique access to these two technologies (additive manufacturing and SM/PM), as well as to attract investors in order to gain more funds. The purpose of this terminological choice is quite well expressed by Dr Benedetti:

"*It's a way how to alarm people that there is something new in the market, but many times also like in this 4D printing, it is not absolutely true that new thing has been developed. Truth is that MIT department of additive manufacturing and architecture started to focus more on the developing of smart materials and its possible applications via 3D printing using time for self assembling and they called it 4D printing because its and attractive way of calling it and it can potentially get also more investors like if they would call it 3D printing of smart materials or fuse deposition modeling, which can assemble itself. That is how I see it, that it's certainly a great development, from which we can expect, where additive manufacturing will take a step, what direction, but at the same time it's a more branding and great marketing, which I also see clever from the future realizations of investors.*"

Even if the expression of 4D printing sounds catchy and interesting for investors, lay people have no clue what 4D printing means, and thanks to the controversial terminology they cannot even understand what they can expect from this technology. 4D is a very misleading term, and certainly we cannot expect that the matter it deals with will behave as "programmable" in the manner that a computer is. When we ask a computer to do something, it will happen 100% as we "programmed" it. Another way of looking at 4D printing is by identifying certain biological rules as its basis of behaviour, although this is not completely right either.

4D printing is a combination of engineering and biology. I am going to outline the concept of being "programmable" in Dr Lewko's words:

"*That's what people do, they're taking a seed of weed or whatever and program it in the sense that they cultivate better types of weed, hoping that they get more food or whatever as a outcome, but it's not the programming in the sense as we understand programming in the sense like an apple computer.*

So exactly we tell machine to do this, that and that [...] and finally you'll get machine to do exactly what you wanted. But programming in this biological sense mean, that you somehow push the thing to get them to wanted directions but you can't really tell completely the results. There will always will be a variety of result, like all of us look different, also we are the same types of beings but, when you get children you can never [...] they will be similar to their parents but they will not be the same so that's the biology as a much wider variety and programming in biology means that you can get somehow very close to your target, but the target, you can't really achieve the target easily and completely, where in engineering it means that you'll get yourself early to the point you want if you do the things right. And that's the thing about 4D printing, if the programming will go more to the biology directions, the things will become more fuzzy and if it will be purely engineering approach, things won't get that complex but usually they will become more specific."

Thus 4D printing can be seen as biological in terms of its utilization of the natural properties of smart materials and in its ability to predict how a materials will behave under different circumstances. Many forms of engineering today are too strictly intertwined with particular ways of working to be able to work with materials operating under natural laws. Understanding this is essential for understanding the linguistic controversies in the matter of the name of the 4D printer.

Following Nelkin's (1995) idea of the "classification-continuum", we can evaluate the current development of 4D printing technologies on the basis of their controversial qualities. This process takes place at a level which consists of controversy among existing scientific models and ways of explaining alternative technologies. In this sense, all scientists in the field of additive manufacturing are using different technical designs to print smart materials. The alternative name, 4D printing, seeks to merge all the existing names under this particular one. This terminology originated in the local scientific community at the MIT, who, paradoxically, by introducing the name "4D printing" to resolve one controversy ended up creating another. The fight can be seen as similar to the administration of vaccines (see inoculation theory in psychology, McGuire and Papageorgiu, 1961). The skeptics' disagreement about the term caused the research scientists from the MIT to silence all questions on the subject of their activities. However, as often happens, such moves only encourage more questions. It is thus how these controversies can escalate into conflicts between scientific models and further develop into a controversy about techno-scientific applications with high interest and participation on the part of society. The core of this work is to assess how these controversies and their applications will be developed, and how society is likely to participate in the development and exploitation of this technology.

The author of "Third Industrial Revolution", Jeremy Rifkin (2011), considers additive manufacturing technology as something that saves energy, reduces the demand on logistics costs, and both democratizes and accelerates production. As cann be seen, the imprecise and ambiguous naming of the technology is causing a lot of controversies and misunderstanding among scientists, which is why it is necessary to look at the contexts in which the word additive manufacturing has begau to occur more frequently. In light of the previously mentioned controversies, I am going to clarify how the scientists interviewed understand this technology as a third industrial revolution. Even the notion of a "third industrial revolution" resulted in controversy on the part of the experts. Their understanding is, however, crucial for understanding possible future developments. Scientists, experts, and conceptualizes are key actors in the development of this technology. This is why their expectations and visions for the future can create a credible picture of how the technology might look like in a few years. The experts themselves responded to questions about the future with precision and extreme caution. Their view of the future could be summed up in three aspects, which I am going to now name and then further explain.

The first aspect consists of applying this technology mainly in industry. The second is that 3D/4D printing will definitely not be part of normal households, and the third aspect is in the technical limitations that will make it impossible for this technology to become a mainstream one in the near future.

Here is a statement regarding the future of 3D/4D printing technologies from the head of the Department of Material Science and Technology, Dr Lewko:

"*I think the long time future has to be really in the manufacturing. These hobby approaches are really nice and it's good for the people to thing and imagine how the things are manufactured [...] But these hobby things will stay as a hobbies. But if you think in terms of market, manufacturing is a huge market, billion or trillions of dollars or Euros. So that's what I think is important for 3D printing in the future, to provide manufacturing with the suitable tools.*"

Regarding the development of additive manufacturing, we may truly talk about the third industrial revolution because industry is the one area in which this technology has the greatest application potential. For the private sector, this technology is not so appealing. This is mainly due to the high requirements of competence on the user.

The difficulty of use and the cost of the equipment prevents this technology from spreading to households:

Dr Benedetti: "*If everyone had a 3D printer is a question on its own I suppose? Well I personally think, that yeah, there will be 3D printers widely spread, maybe not in every households but they will be achievable for everyone who wants them, whether for a reasonable price at home, whether in supermarkets or a special print service which will be in every Bezirk like today are these similar with a 2D print.*"

What we learn from this statement is that although the technology of 3D/4D printing is not going to be a normal part of regular households, it is going to become definitely more and more accessible to ordinary people. User complexity is an important thing to consider when thinking about the extent to which this technology can become a part of everyday life. The essence of the problem lies the inability of the lay person to use such a printer. Additionally, all the materials needed for printing require proper storing. I addressed user demands and ideas of user centered design when describing the opinions of Dr Lewko:

"*[T]o design thing you would need to keep the drawings and so on, so that's not easy so it's also a more software side, because people to know how to write an email but only few people know how to make drawings on the computer and even fewer people know how to make 3D drawing on the computer and then the number of the people willing to spend time is not that large I think. In my opinion it is a hobby and it will stay the hobby but it's not a future for the people to have it in ordinary households.*"

Is it even necessary for 3D/4D printing to become a part of the standard household? Experts believe that it is not possible or even desirable because of the possibility of abuse. This technology will still have to go a long way until it is possible to conduct "plug and play operations". Until then, the opportunity to work with it is strictly in the hands of scientists, and possibly some hackers and domestic inventors. Because the use of this technology requires a high skill level, there is very little chance of it being abused by lay people.

Dr Sonquist's response to a question about printing weapons with the help of 3D printing illustrates this controversial aspect of the third industrial revolution.

"*This is just a revolution and people are trying to do whatever they see and want and I think that that's only at the beginning, maybe the problem will be when 3D printing of metal will be too easy, as I said when it will be just plug and play, than that could be a danger because people can print out whatever they want, now it needs lot of skills to work with metal printing but I see that there is a big gap regarding this but that's only on the beginning. For the future I don't see that it will be the revolution, that it will be abused by the people.*"

This raises the question of what the consequences of the revolution will be. We already know that the main potential and expectations will mainly affect the revolution within industry. Conversion is not going to take place overnight, but rather will run its course more gradually. The simplification of maintenance and the reducing of operating costs is also in sight in the near future. What can this technology help solve? Because of a multiplicity of different foci between individuals, scientific collaboration sometimes lacks real efficiency. In this regard, this technology can be a pragmatic ground to strengthen interdisciplinary cooperation. The technology of 3D/4D printing creates an area where doctors, biologists, athletes, builders, designers, engineers, computer scientists, material scientists, artists, and many more can freely collaborate. Thus far there exists no field that forces experts from such a broad range of backgrounds together.

Dr Hyams outlined this idea as follows:

"Industrial revolution, it's not a revolution but it can be a significant step forward its already exploited by many companies from many areas form industry but not yet everybody can benefit from it. I just talked to colleagues yesterday and I was excited in which new areas our comparably small company goes now, when I begun two and a half years ago, we've been like ok [...] this area is not interesting for us, they're focusing on metals and we are doing ceramics, or they are doing big parts and we are you know rather doing a small structures but know we're in touch with all these companies and we are finding out that there is so many points where our technologies or interests are overlapping and I am sure the trend is going to continue and I think it's a nice term and I heard it in so many talks and lectures an many articles this industrial revolution. It would be one if it really brings manufacture to the customers home. But I don't see it coming in the feasible future."

The most likely scenario we can expect in the development of this technology has to do with both interdisciplinary collaborations offering a great environment for it, and setting up a network of 3D/4D printing for general public, where one will be able to order something to print. This is the expectation of all the interviewed experts involved in this project. As Dr. Hyams puts it:

!It might come in a let's say in the way that service providers a may be that the machine is the Billa or it's a completely new lines of business. As it's done now that there is some service bureaus and they're providing this service of printing out parts in every town so there is a real network. Or what's also quite interesting is this networking of different service providers, people who are having facilities or equipment to print out the parts. I think there was this fundraiser in kick-starter, where they been thinking about building a network, that people can't access. Machines somewhere in country continent, because they see ok, so there is this machine I need and I can go to the internet find it order it and get shipped. So that could be something, that people are imagining right now [...] or of course another option is really bring production close to the customer by the network like you just mentioned, by bringing 3D printer to a every bigger supermarket."

This view of the possible future developments of this technology outlines a high possibility of the emergence of a new type of market that is different from what we know today. In the event of additive manufacturing reaching such a point, market expansion products can be produced and sent to the current global market to sell as a 3D model of the product in electronic form. Regarding the controversy of understanding the "third industrial revolution", we have seen how important scientists are in creating the future simply by virtue of their presence in the process of shaping the future of this technology.

5.1.2.3 Inscribing Additive Manufacturing/Philosophy of Engineering Technology

After describing the engineering philosophy that scientists create for 4D printing technology and the "in-script" which follows this process, I am going to elaborate on how effective this "in-script" can be and how this technology can be misused. In the next section, my aim is to continue on to controversies in the conceptualization of this technology amongst scientists. Firstly I am going to outline the role of scientists in modern society and what constitutes risk for them, and after this I will continue with the experts and their views of the technology of "4D printing" as well as what impact it may have on framing the technology.

We would like to believe that scientists are governed by motives of organizing modernity, as Law (2004) describes:

"*In one way or another, we are attached to the idea that if our lives, our organizations, our social theories or our societies, were 'properly ordered' then all would be well.* " (Ibid., 4-5)

However, it is likely that if we consider scientists as people who are resourceful in their activities, and as people who are governed exclusively by rationality when doing science. This is misleading and controversial, because history has shown that the efforts of scientists are not always converted into the perfective fulfillment of the objectives which gave rise to the effort in the first place. What is the key to knowing whether the development of a technology will be productive or destructive? There are various theories to state that a false prophecy can be fulfilled through people's belief in it (Merton, 1948). This social phenomenon is called a "self-fulfilling prophecy", in contrast to "self-refuting predictions". In the context of our problem, experts who claim they are trying to find a parallel for the development of 3D/4D in 2D printing may affect future developments by interpreting the public in a particular way. In this scenario, people would have to regulate the number of 3D/4D printers to avoid mass producing objects via additive manufacturing and causing environmental damage.

In my opinion as an STS researcher, it is not sufficient to think that humanity has already learnt from their mistakes, or to believe that it will not make them in the future. It is difficult to decide what the next steps of humanity are going to be because every serious decision can bring about unintended consequences (Merton, 1948). I think that we should not believe in the goodness of people, but rather, we should firmly determine the scope of activities permitted, as is customary in democratic societies. This is why we need to think ahead and find correct legal and also ideological frames that can be used for the advancement of societal progress. Leaving any technological development deregulated and relying on the awareness of citizens may be bring about unexpected damage. Ted Nordhaus and Michael Shellenberger (2012), in "Futures of Modernity", describe the first modernity as a condition of increasing the welfare and prosperity of society through the development of the welfare state, law, and other normative frameworks. From this, a second modernity develops, which sees institutions and other frameworks as the norm.

This attitude conceals great danger, as described by Beck (2008) in terms of the "second modern risk". The risk lies in the dysfunctionality of the old thinking associated with the first modernity, which goes on to cause the breakdown of old institutions. In this way, the whole foundation of modern civilization is undermined, together with the state and market economy. Each of the resulting crises grants even greater power to the state and to those who live in wealth. Thus a thorough reinvention is required in the shape of the third modernity, or third industrial revolution, (Rifkin, 2011): a revolution that will not be only about technology but also about human thinking. With that part, there shall be universally expanding freedom and responsibility.

Within this frame, we can distinguish controversies in the development of technology, as well as contradictions between different scientific communities. These are contradictions that even modern science cannot cope with. These are the key controversies that affect the future development of technology. While these controversies are not insignificant, for the time being we shall not take them into account. Let us believe in the success of the efforts of scientists to make a better world. I am going to explain how the direction of a given technology determines how an "in-script" should be managed. After describing the engineering philosophy that scientists associate with 4D printing technology and the "in-script" which follows this process, I am going to elaborate on how effective this "in-script" can be and how technology can be misused It is necessary to remain aware of and to keep in mind the full extent of the controversies that surround the development of this technology. This is why the remaining paragraphs will be dedicated to appropriately framing the scientists' attitudes with reference to this notion of causality. I will start with the importance of the visions of the future that may predetermine the future itself.

Until now, we have considered how the technology is used and what kind of a "mindset shift" society, at least according to my interviewees, is struggling with at the moment. Through a critical look at the title of this technology, we got to glimpse the extent to which this technology is revolutionary. It was essential to define the history of the technology in order to understand how its future may be shaped, because the future is born from the past, and the present links the past and the future (Melucci, 1996). When considering this issue, there is a claim that the future is just as important to the present as the past is, and similar claims also say the future affects past through the present.

Viewing 4D printers through Melucci's (1996) eyes presents a very interesting scene where skepticism and outdated thinking hinders the penetration of new technologies into everyday life. Overcoming skepticism and "mindset-shifting" are essential for rethinking change in order to adopt and use new technologies. There are many stereotypes that are based on the experiences produced by interaction with other technologies: stereotypes that hinder development and impede progress. I am going to demonstrate this with one example. In 3D/4D printing, the action is still called printing, although Gutenberg's printer has no longer anything to do with the process, at least not mechanically. The word "print" evokes the image of a 2D printer, which warns us against the pollution caused by that particular technology becoming cheaper and increasingly more accessible. Such a vision can help the future either to be created or reversed before it has even arrived. A couple of examples of this that have already been mentioned are Merton's "self-fulfilling prophecy" (1948) and "self-refuting predictions". What matters is how we deal with this vision. We can accept the fact that people are just people and reconcile with the subsequent developments, whether they be excessive abuse or awareness of the consequences until the end. Perhaps the best startegy would, however, be to learn lessons from the past and to regulate the excessive use of technology even before it occurs. One thing is certain, our scientists predict that when this technology becomes more widely available, there is a great risk of people creating massive amounts of environmental waste. As the technology of 4D printing develops, no matter how big the risk is, it will become increasingly necessary to also develop 5D printing with the ability to self recycle. The linear development of production materials and the recycling of materials are necessary conditions for the creation of sustainable development, as well as for controlling the second modern risk (Norhaus and Shellenberger, 2012).

It would be really nice if Europe's future development of environmentally friendly methods of production was successful in fulfilling its objectives. However, whether this will be the case is not possible to answer now. One thing is certain: this technology will accelerate that development, although we cannot tell in which direction. Experts see the benefits of this technology in terms of its capacity to save material and to produce almost anything. This is why its main application in industry is simplifying the maintenance of production facilities alongside the production of new designs. Precisely manufactured products with endless variability for each user, such as in biomedical applications or in mass production, give a whole new dimension to manufacturing and production. All these marketing facets of this technology will be uniquely important for each product sector, and every business can benefit from them. The researchers assume that in the near future this will affect the overall market of the additive manufacturing technology. However, this will not bring the technology closer to people—rather, it seems the opposite will happen. We can imagine this development will be sudden: suddenly almost everything will be produced by 3D/4D printing. The advantages of additive manufacturing are going to be new types of foods, futuristic furniture, and cars that has a more powerful engine and a more aerodynamic body. Nevertheless, people will pay for these products through companies instead of "printing" at home because they it will be not affordable or efficient.

The consequences for society will definitely not be to the extreme of people producing completely "new things" because that would require a very sharp mindset shift. Demands on the quality and standards of products do not allow the market to become flooded with unspecified products. Although there are certain people who could find unique applications for additive manufacturing, the percentage is very small, which is why there is lack of demand for new designs and products. The changes that this technology is about to bring will remain hidden from public sight inside the production halls. The market cannot be changed overnight. What will change instead is the structure of the division of labor in the production process. Dr Benedetti said that he completely understands why the MIT chose to merge additive manufacturing and architecture. It is because 3D printing is used from the start in architecture as well as any construction processes. This was done in an attempt to show how the resulting structure will look like in order to further the development of new uses of additive manufacturing to create anticipation and buildings alike.

This remark from Dr Benedetti is significant when it is taken into account how many craftsmen could lose their jobs because of 3D/ 4D printing, not only in construction but also in other industries. The spread of the technology could even encourage some countries to ban the use of 3D/4D printing, just to keep employment levels up. Dr Hyams nevertheless thinks that this technology could help keep jobs in Europe owing to efforts of maintaining world leadership. The way political forces accede to the framing of additive manufacturing in terms of cultural and social standards is an essential aspect of the development of this technology.

In state of the art and theoretical sensitizing concepts[25], I have outlined how technologies are influenced by norms and what forces can manipulate and frame technologies. In Winner's (1980) analysis, technologies can be political in two ways. The first way is a by means of technology that influences society in political manner by its design or arrangement. The second is in terms of "*inherently political technologies*" (Ibid., 128)

Whether 3D/4D printing will end up leaning toward the first or the second way depends on what kind of a stance policy-makers will take, and whether the expected development of additive manufacturing will be similar to that of the 2D printer or not. If this scenario is repeated and society creates regulations only after problems occur, we can expect overprinting and excessive pollution. The technology would in this scenario demonstrate its destructive face. However, if the potential of this technology is framed correctly from the beginning, it has a chance to become a constructive technology. Akrich (1992) says that the technology itself hides

[25] See Chapter 2.5, Normative Politics of Technology

its script. According to our project, this is a tremendous utility in this technology. The program that can be used for a socially useful purpose, in practice, is contrary to its anti-program, which can involve the printing of guns and wasted resources. Akrich (1992) treats the notion of a script with great importance, and considers it an important part of the innovation course to be followed. The experts interviewed in this project believe that this technology will not be a disruptive technology (Christensen, 1995). It will only be an addition to other technologies: only a partial thing, and that is why it is not necessary to in-script 3D/4D printing.

Technology is constructed in a societal context of using it, and it is influenced by interpretative flexibility, relevant social groups, and controversy with alternative interpretations of the technology that can cause public controversies by disturbed relationships between science and society. It is important that the third industrial revolution is based on the democratic principles of equality and freedom, but it must also hinge on civic duties. These principles must be developed to avoid the second risk. Modern technology could also prove very beneficial. This result can be achieved only through a continuous dialogue between politicians and voters, as well as between inventors and consumers. These controversies can be overcome through a political consensus that is based on a potential solution which depend on the framing of the problem. This problem addresses the acknowledging of a social and cultural dimension of scientific knowledge with regard to the distinction between a proper and an improper public, invited to the table for discussion. With this tactic, changes can be introduced to the governance of science, transforming the setting from a hierarchical one to a network-oriented one by focusing on four distinct points: framing, vulnerability, distribution and learning (Jasanoff, 2008).

Through this discussion, we come to the question of what direction the technology ought to be in-scripted toward. This question is the right one to ask because the technology is not yet black-boxed, and thus we can see how it works. We know that today there is a phone screen that is able to repair itself (such as the LG G Flex[26]). China is also beginning to print the building blocks of livers,[27] using a texhnologywhich is indeed only at the beginning but has the potential to develop very quickly. It is a combination of self-repair capabilities and a bioprinter which could in theory be able to treat an otherwise fatal crash injury or to create a super soldiers. Printing more resilient organs might sound too futuristic, but we can regardless follow future scripting efforts (den Boer, Rip, and Speller 2009). The advances discussed could, however, give rise to many controversies that will not only apply to marketing and policy aims, but also to

[26]See web page http://www.dailymail.co.uk/sciencetech/article-2478260/LG-G-Flex-phone-unveiled-SELF-HEALING-cover.html

[27] See web page http://www.3ders.org/articles/20151009-chinese-scientists-3d-print-building-blocks-of-liver-on-course-to-3d-print-entire-organ.html

various ethical contradictions. Now, I will advance to regulations and the imaginations involved in de-scripting the black box.

5.1.2.4 Regulation/De-Scription and Breaking of Black Box

In this chapter, I will address regulations and the imaginations involved in de-scripting the black box.

In Austria as well as in the European socio-technical context, scientists generally enjoy a privileged position in regards to the production of new technologies, mainly owing to their penetration to the public through market mechanisms (Friedman, 1981). Their importance in my research lies primarily, as Dexter (2006) notes, in the fact that scientists do not necessarily reflect élites or their attitudes. In this sense, experts can be considered to be influential personalities in the development of technology with the ability to see things in a broader context, unaffected by political and economic goals. These are aspects that our scientists a special insight on inscription through objectivity and skepticism. Their main concern, before talking about regulations, is to not limit research. Dr Hyams, for instance, when discussing regenerative medicine, rejects any and all regulations, as he sees great potential in this technology.

Let us recall his words to flesh out this view. Dr Benedetti considered the issue potentially fatal, as overly strict legal regulations could even completely stop the research.

"*This is very hard question to answer*[28]*, on one hand scientists need to have a free hand in development because any regulation really slows down the research and sometimes it even stops it but on the other hand we don't want people abuse this technology whether is 3D or 4D printing, because it could bring fatal outcomes.*"

As already stated in the section dealing with Dr Benedetti's statements, the regulation of 3D/4D printing is quite problematic, mainly due to the technical performance of the process and its in-script. In a somewhat idealistic sense, the solution should perhaps lie in designing regulations for commercial printers, where regulation could consist of an in-script inserted into the printer by the manufacturer. The in-script could thus limit what the printer can technically and legally produce. It could also have the capacity of detecting potential abuse. Of course, this view of effective regulation is very superficial. It was envisioned by the interviewed experts who could not agree on any working regulation scheme for how additive manufacturing should be in-scripted.

Due to the wide possibilities of application of this technology combined with high user demands, it is possible that this technology cannot be "black-boxed" at all. When considering

[28] *"...[H]ow it can be regulated in the future, that's one of the aspects. So really just hypottetycli ,how could you see the balance between innovation, democracy and regulation. How would you imagine, that this could be regulated and still kind of freely developed."*

regulation, it is necessary to keep in mind not just the cultural contexts of the use of this technology, but also the way society takes in scientific knowledge through modern advances. Modern society reelies on the difference between those "who know" and those "who do not". Thus it can be said that a contradiction between high culture and pop culture exists (Matthew Arnold, 1956). In other words, or in the words of Max Weber (1956), the view of scientists administers the hallmark of objectivity through a streamlined way of creating knowledge by scientific work, and an institutionalized academic status gives the researchers a lead in defining the potential risks of upcoming technologies. What would Weber say about the 4D printer if he had never even experienced a 2D printer?

Ulrich Beck, in "Risk Society" (1986), is devoted to the idea of the "redefinition of the hazard" as a socio-technical relationship affecting modern society. This is when a major weakness of modern society is viewed as a fast development in science and technology that proceeds too fast for the unintended effects or linked to the progress to be properly assessed. Scientists were originally just privileged persons capable of defining the undesirable effects of technology due to their streamlined institutional position, which in fact ought to be one of the building blocks of of institutional reflexivity (Giddens, 1991). This institutional reflexivity should take into account the socio-technical context of technology-in-use—otherwise, it might make any proposals regarding the effective regulation of this technology impossible. Effective regulation means not hindering development while preventing abuses. Researchers and their knowledge play a major role in the modernization theory (Bernstein, 1971), and they should be targeted with precision. Mainly in the development of technology and its use in practice, expert opinions are very relevant, especially in with regard to the controversies that affect future development. Quoting Dr Lewko:

"*We want freedom, but freedom also means you can do stupid thing, depending on how stupid people are, we need to shut down the freedom, that's in many respects so there is no one, perfect answer [...] because more you regulate you abuse the freedom of people.*"

I need to point out the importance of the black box in shaping the use of technology in practice. As we can see, 3D/4D printing technology is very problematically framed, and it is almost impossible to do an"'in-script" to the extent where the technology becomes black boxed. This means that the technology that has a high probability of abuse. This probability lies not in producing weapons,—as has been said many times, it is possible to create common weapons nowadays without the use of additive manufacturing. Dr Lewko notes one very important aspect of the possible misuse of 3D/4D printing, which connects the possibilities of the internet to the variability of using this technology. Free access to information allows almost anyone to download instructions for how to make a bomb or a large-scale weapon. This means that, after the popularization and expansion of additive manufacturing, the possibility for someone to download 3D sketches of weapons expands. This will bring the general issue of abusing information and copyright to another level.

Dr Lewko "*[S]o it's not only hardware but software is as problematic in this respect*."

Thus, in terms of hardware and security, we can rely on high user demands and the inability of the lay person to successfully handle such a printer. During this period, we need to work on software security to prevent the misuse of technology before additive manufacturing develops to the stage of "plug and play" functionality.

Since scientists cannot even imagine how the kind of functional regulation which would effectively prevent abuses should look, it is difficult to talk about imaginations or the de-script(ing) of 3D/4D printing. Akrich (1992) defines de-scription as a way of how to interpret the different uses of technology in contrast to pre-conceptualized interpretations. Thanks to this idea, we can anticipate numerous possible forms of abuse, and use these to create an imaginary in-script for this technology. Scientists do not know how society should effectively regulate the technology, but we know their attitudes. This makes it possible to predict a direction. Because of this, I can imagine how in-script might look, and it should thus be easy to construct it. I have listed a wide range of potential abuses associated with the technology. The ideal in-script would be based on freedom for those who want to do research with the technology while limiting the actions of ordinary users and corporations. These limitations would mainly deal with the shape and usefulness of the printed goods, but also with limiting the quantity of environmental waste. Thus regulation should be based on the differentiation of users between a) experts that demand a high capacity to work with the program, and b) ordinary users who work with black-boxed printers. This black-boxing can occur either through "fax and copy staff", some other kind of guardians responsible for any misuse, or through a software program that performs this function. If an issue arises, the software should block activity across printers and send a message to the firewall, police, or some other body of defense.

Experts interviewed in this project point out that with any new technology, the danger of abuse arises. This danger is that what Dr Sonquist describes as:

"*This is just a revolution and people are trying to do whatever they see and want…*"

Because the usefulness of this technology does not yet surpass the capacities of existing production methods, and because of the lack of a killer application, scientists are not afraid that the technology could increase the number of illegal weapons. I am referring to Dr. Lewko's statistics of regulation. Thus, as Ing. Vogele mentioned, the statistics indicate that if someone purchases a 3D printer for their home, in a few months' time that person will be no longer interested in printing anything whatsoever, as he or she will have run out of ideas of what to print. The proportion of people who would abuse this technology is negligible compared to the number of all other existing, non-abusing users. However, if the mindset of people suddenly progresses and at the same time, this will also increase user demand, after which the scenario described by the "Frankenstein complex " might take place to an outrageous extent. Similarly, after World War II and in the 1970s, car accidents were not considered to be a problem for manufacturing or design. Instead, the drivers themselves were always considered responsible for the accident.

In the context of parallels with 2D printing, we can imagine "de-scription" (Akrich, 1992) which could result in a similar scenario. Cheaper additive manufacturing technologies are going to bring the technology closer to society. Accessibility without appropriate regulation may result in unintended consequences, as was predicted in the sci-fi tale "Kiosk" (Sterling, 2007). What is different when comparing "Kiosk" to reality? What prevents this technology from resulting in a dystopian scenario similar to the one imagined in "Kiosk"? The unavailability of 3D/4D printing technology or the high user demands? Ing. Vogele comments on the issue superbly:

"*[T]here is so many people, who buy today and there is the biggest spread of this open source, low cost home fuse deposition modeling printers in terms of few thousand of Euros maximum or a few hundreds if you're more in to assembling it yourself and tuning it up. But theses doesn't allow you to do much, there is usually no support materials so there is problem with avoiding shapes and so on.*"

In this way, we can see how high user demands are becoming an in-script of this technology. The unsustainability of modern life to which Nonorrhaus and Shellenberger (2012) refer cannot cause major problems. The view of modern risk and the risk of the "Frankenstein complex " (Asimov, 1978) are still present. Ing. Vogele points out that if this technology finds its killer application, it will definitely give rise to new developments as well as an increased use of this technology, which will naturally also lead to the cheapening of this technology.

We must be aware of the progress that mankind has achieved in recent years, giving rise to something such as 3D/4D printing. It is necessary for the third industrial revolution (Rifkin , 2011) to be mainly a revolution of spirit that eliminates the political cynicism of the "second modernity", which refers to a cosmopolitan modernity based on an imagined risk that threatens all.

"*Without a deep and abiding appreciation of modernity, of the remarkable journey that the human species has taken, one cannot appreciate or even see the remarkable common investments that our predecessors have made through the institution of the state. And without seeing those state investments and the context that makes modernity possible, one cannot embrace a meaningful role for collective action to shape the future.*" (Nonorrhaus and Shellenberger, 2012 ,105) Thus awareness of the progress of modern society and the informed use of the conveniences of modern times can be the key to the proper framing of this greatly variable technology.

We should see the interconnectedness of the development of various technologies, and understand this act of development as the interplay of several existing technologies. In this sense, I see 4D printing as the killer application for 3D printing and smart materials.

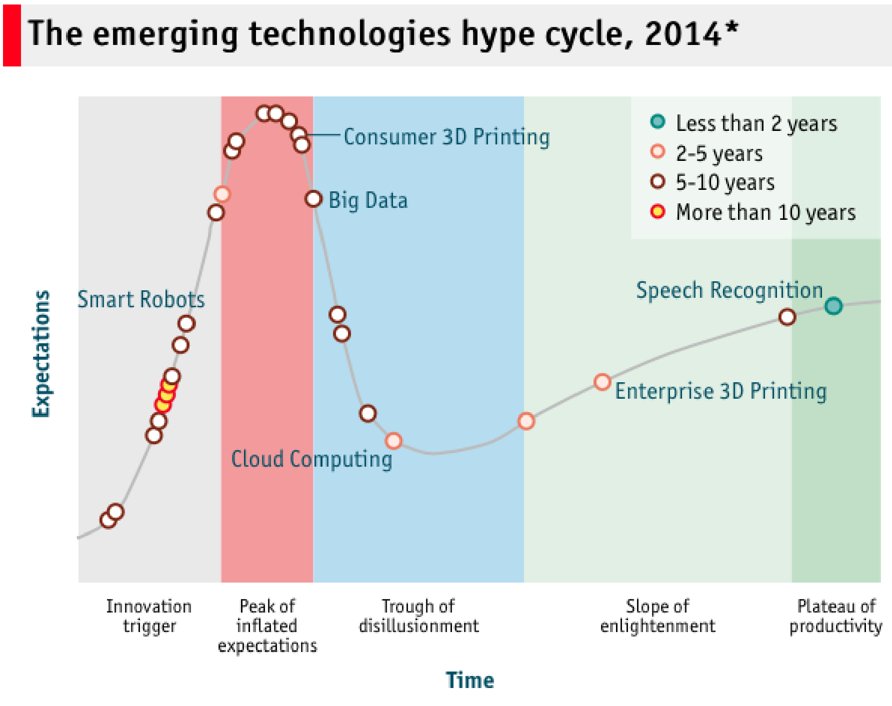

Figure:1.3. http://www.economist.com/blogs/graphicdetail/2014/08/daily-chart-17 (Accessed on September 1st, 2016)

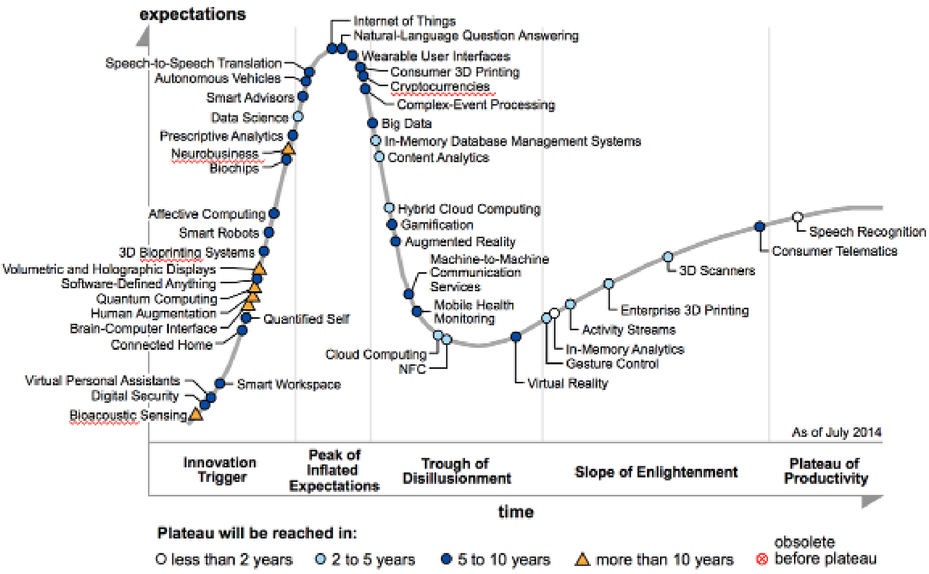

Figure 1.4. http://www.economist.com/blogs/graphicdetail/2014/08/daily-chart-17 (Accessed on September 1st, 2016)

Gardner's hyperbole seems to me to be far too techno-deterministic (Veblen, 1964), although it makes for a very interesting approach to market research. It is useful for our issue in terms of how the development of technology is described. Every technology goes through a similar process of development: the long cycles of five stages.

The first of these stages is "innovation trigged", which is characterized by a sharp increase in the expectations concerning a given technology, as has been the case of 3D bioprinting systems. The second is the "peak of inflated", when expectations exceed even the most realistic possibilities of a technology, such as in the case of consumerist 3D printing. The third is "through of disillusionment" when expectations are rapidly falling off through the obstacles of development, as is the case with the difficulty of bringing 3D printing to the household, as it is not user friendly. The fourth stage is the "slope of enlighten", which addresses the real requirements placed on the technology and thereby demonstrates what it can truly do. The fifth and final stage is the "plateau of Productivity", where expectations are growing on the basis of the proven usefulness of technology.

If we apply this techno-hyperbole of 3D printing to 4D printing, based on the interviewed experts' thoughts, it is currently at the stage of "through of disillusionment‶. In other word, the technology has survived the period of the greatest expectations and is gradually meeting the limits of its potential. The main problem is, as already mentioned, that the killer application still waits to be discovered. This means that once the expectations about the future of this technology have been somewhat lowered, there ought to come a period of slow development and advancements, preparing this technology as a tool for the future.

The views and anticipations of all stakeholders in the field of STS are essential for a better understanding of this technology. Techno-hyperbole interconnects with the issue in describing the technological aspects of the market and its relation to other current inventions. It can be divided into two innovative linear models: the technology market push model and its opposite, the pull model.

The technology push model draws on the following: basic research, applied research, technological development, and applications. On this axis, we could place the 3D/4D printer in acrossroads between applied research and technological development.

Fundamental research can already be considered complete, and it has been a long time since the question of whether we can be print polymers or steel by means of 3D printing was discussed. Even lay person knows that all of this is reality now in 2016. The market pull model offers the following as anchoring points: market needs, development, manufacturing, and sales. We can place 3D/4Dprinting technology on this axis in this stage of its development. The need has arisen to find cheaper methods of production, which has led to the development of this technology. However, the development is still far from this technology being mass-produced or sold to end-customers.

Nevertheless, the 3D/4D printing technology model cannot be determined accurately because of the controversial link between 3D printing and smart materials. It is especially problematic in the market pull model. The need for the technology arose mainly because producers want to create new products with lower material costs, less technical equipment, and less energy. Thus the impetus for the development of the market for this technology did not originate on the side of the market where the end-user plays a key role, but on the other side: that of the inventors, corporations, and businessmen.

What do these models offer in terms of clarifying the future development of this technology? They shed more light on the evolution of the progressive technology. Two innovative models are mentioned in reference to hyperbole, through which, if applied to Nelkin's (1985) typology of disputes, we receive a comprehensive framework for the possible future development of this technology. The first dimension of the controversy arises from the fundamental ways in which people look at the world through different social, moral, and religious interpretations of technology. What this tells us is that the current mindset of society does not focus on the sudden development potential of this technology to the extent that it could penetrate society on any given day. This reality also prevents the market demand for new and non-traditional products. A second typology consists of the daily struggle between political and economic objectives with regard to the issues of what is right for the environment. This tells us that the marketing objectives geared toward mindset-shifting have not generated enough demand from the general public for non-traditional 3D/4D printers yet. Reducing production costs and the incorporation of additive manufacturing in the commercial sector is going to add a completely new value to manufacturing. However, traders will prevent independent inhabitants from using additive manufacturing on their own through the price of the printers, along with the price of the materials necessary for printing, and most importantly, the information required. Thus the development situation comes into conflict with political objectives, which should carry out policy decisions that will affect future generations who are now without a voice or a choice (Adam and Groves, 2007).

5.2 View of Hackers

For the section dealing with the hackers, I will proceed in the same way as I did with the experts, the only difference consisting of a more comprehensive description in the appendix (10.4 Hackers (Group A) and 10.5 Hackers (Group B). This section briefly outlines the specializations of the hackers who took part in the focus groups, as well as specifics regarding the differentiation of the groups. In the next subchapter I am going to try to analyze the hackers by making use of the same STS concepts that were used in analyzing the expert interviewss.

Hackers are key figures when it comes to getting a preview of the ways in which non-expert users may conceptualize the technology. It was very difficult to gain access to the hackers. I initially orchestrated a search for them online, which involved several weeks of online communication the content of which I do not engage with in this analysis. The role of the communication, in addition to searching for willing participants, was to determine their familiarity with the subject of the research. I made sure that I did not affect their views, and the participants were also given the opportunity to properly prepare for the focus group. I was trying to map their worldviews and attitudes regarding the technology, and I subsequently divided the participants into two groups on the basis of their individual approaches to institutionalized science, as well as their attitudes towards the technology itself. I made use of online communication on forums in order to ensure the efficient working of the focus group studies I would conduct. Obviously, I also attempted to avoid the obstacles that could negatively affect the whole course of data collection or prematurely terminate debate. Through this online communication, I managed to identify the participants. The controversies outlined by the scientists during their interviews were great asset in framing questions and processing data.

There is one unifying quality about the hackers that must be acknowledged in order to understand the peculiarity of the focus group in this research. Hackers are wrapped in secrecy. They are somewhat like the pirates of the past: hackers have just exchanged the ocean and their ships for the internet and banks. Banks and the internet are not only spaces of action for these people, but because of the representation they receive in the media, hackers are most well known in relation to these spaces of action. Hackers and the non-institutionalized world of technology development are a significant part of science and technology.

The hardship of dealing with the participants was rooted to their being very sensitive to matters of privacy and the processing of research. I had to assure them that any information shared with me could not be used to identify the participant. This I ensured by means of the distribution of participant identifiers and randomization of data obtained from each individual. This ensured that even if someone came across my research notes, they could not get to the identifying data of the individual participants. Thus through an informant, I managed to establish online communication with a number of hackers who deal with 3D/4D printing. These weremostly people participating in the Vienna 3D printing meeting, as well as some of their friends who did not attended meetings personally. The participants of the 3D printing meeting also included members of local artistic subcultures engaged in the production of non-traditional sculptures, such as those produced with the help of 3D printing. Unfortunately, the hackers from Group A did not allow me to take a photo of their work to ensure their privacy, which was agreed upon before their participation.

During the period of online communication I was mainly interested in how the hackers engaged with 3D/4D printing and what their attitudes towards the technology were. Based on these two criteria, I divided the participants into two groups, as further clarified in the chapter 3.2.1.2, Focus Groups with "Hackers". This allowed me to bring together people with shared interests, which created the conditions for a fruitful debate. This allocation of participants also allowed for the me to be adequately prepared for the debate. It helped in preparing an outline and establishing the key issues of the debate. This data collection method ensured empirical observation through a frame that had been adapted to be able to capture the specificity of the different groups, not individuals.

Science gives us tools, but it does not tell us about how to handle them. This creates contradictions between the moral values and the technical capacities of actors in society. The scientists often talked about the possibilities associated with the technology of 3D/4D printing. The scientists cannot fully imagine how this technology will be used in the future, since even if they do design the technology, they often cannot accurately imagine how it will become de-scripted (Akrich, 1992).

The hackers work with additive manufacturing technology, and their view of things can help clarify some of the questions that the scientists could not answer. This is especially true in the case of sociotechnical imaginaries, as hackers are certainly closer to society, and they definitely perceive the technology differently in many ways. These ways invclude ideas of what effective regulation could really look like, and what combination of 3D printing and smart materials might lead to a devastating abuse of this technology. An important notion which the two hacker focus groups helped me discern related to their visions of the future. Looking into the future, whether a utopian or a dystopian one, can tell us a lot about the future direction of technology. There are three major conflicts in play. These are between the scientists' skeptical views, the view of 3D/4D printing as a God particle (as per Group A), and the dystopian view of Group B.

While the scientists interviewed offered me a somber look at the issues at hand, the hackers showed me a perspective that arises from experience with additive manufacturing. On the other hand, hackers also offered me insights into how this technology is framed. For example, high user demands began to disappear after people working with this technology directly demonstrated some partial actions. We can also mention the limitations of the technology, which are the uncertainty and inability of the printer to produce the product in exactly the desired dimensions. My participants in Vienna came from a multiplicity of backgrounds, and those with a stronger professional affiliation to academia often demonstrated views that were more similar to views of the experts. I especially noted the similarity of views within the students. It has become evident that whether the student agrees with the official science or not, he is affected by it to a certain point. Thus, the pathos of the participants more inclined to adhering to the views of scientists often lapsed into utopian ideas. I pointed out the fact that a significant portion of the participants had learned how to work with 3D printing by self-learning process. In other words, the participants in these focus groups were not formally trained to work with 3D printers.

Both groups were more or less homogeneous, and the division into two groups was not intended as an artificial form of separation. On the contrary, the aim was to promote communication, which led to the participants discovering common ground as well as differences in equal measure. This is why duringboth focus groups, I was going through the same controversies yet with a different tact. Among other things, this helped me to gain all the necessary data so that I could explore the issues of additive manufacturing technology and its possible future developments. More information about the groups can be found in the appendix (10.4, Hackers (Group A) and 10.5, Hackers (Group B).

5.2.1 Worldview of Hackers

I am now going to elaborate on the core controversies that both of the focus groups outlined, with a focus on the slight deviations in their assessment of the controversies. Participants from both groups were invited to participate on the basis of a wide range "hacking" practices, promoting the technology's development through practical measures. With the hackers, I did not specify in detail what projects the participants were currently working on in order to protect the identity of the participants. A number of the "hackers" also did not want to talk about their work. For the participants of Group A, their main form of access to 3D/4D printing consisted of institutionalized use through companies or academia. This was reflected in the idealistic view of the participants of the technology being tool for making the world a better place. Paradoxically enough, in this focus group, the discussion strayed to the topic of access to the technology of 3D/4D printing for non-institutionalized uses, such as in the realms of garages, ateliers, and so on. For these participants, mistrust was caused by commercialized science. This increased their fear of a dystopian future (Sir Cuestas Moor, 1516). This is somewhat ironic, considering that the other group's approach to this technology was much more constructive in overall comparison. While at first sight, these groups acted in diametrically opposite ways, both groups had more in common than not.

First, rather than tackling the various controversies head on, I consider it important to point out the common ground between the two groups, from which the description of controversies is going to unfold. All the participants involved in the focus group are people who are working with additive manufacturing in various forms, and thus have a good understanding of how the technology works and how it can be exploited. Their practical experiences, either directly in the case of the first group, or indirectly in the second group, were in contact with the commercial sector. The first group (A) saw the technology more like the prospective users of this technology, similar to lay people, working with the most modern technologies either in their jobs as consumers. In the second group (B), participants came from fields where they worked with the technology in their daily jobs. Nevertheless, this technology was used only in a secondary role in their work. For example, some of the individuals who were part of the second group included designers who work in advertising agencies. Despite the fact that the first group looked at the technology in a rather utopian way in comparison to the other group, both of the groups' viewss were based on reality.

The scientists' claims about the possible future evolution of this technology do not sound too exaggerated to the focus group participants. Scientists have already pointed out the wide range of application of this technology which may become a double-edged sword. T hackers rejected this idea. I would not, however, consider the opposing view of the hackers as an obstacle in the conceptualization of the technology, but rather as a way of looking at this technology from a number of different angles, and of using these views to gain detachment with regard to the development of this technology

The disagreement between the groups did not reoccur when discussing what kind of an impact this technology will have on the future. Both groups agreed that the technology is waiting for its killer application, and when it comes, the technology will be used much more widely and it will have a huge impact on society. The only thing in that really differed between the groups was the direction in which they envisioned the eventual killer application leading the way.

The next disagreement between the groups was on whether the technology would be used productively or destructively. Group A, the participants of which do not use this technology constructively (i.e. as their hobby), believes that this technology will transform society and push it to the next evolutionary level. Group B, the participants of which work with the technology primarily as a hobby and try to use it beneficial ways, thinks that after the arrival of killer application, the technology is going to irreversibly move humanity to a higher level. However, this group (Group B) is concerned that a higher level will also carry some negative results. Thus both of the focus groups consider 3D/4D printing as the third industrial revolution. They differ only in how they view the overall consequences of using this technology. If the gaps that this technology, as identified by the experts, are successfully breached, the technology could be used in creating a better world. This idea was well expressed by the first (A) group. However, the experts also pointed out the excessively broad application of this technology, which prevents effective regulation and black-boxing, which was further picked up by the second (B) group.

Zygmund Baumnan (2012) reflects on the uncertainty of modern institutions, such as Beck's risk society (1986), and he points out that the category of risk has become a natural part of the society where any regulation is based on the fact that potential side effects cannot be definitely avoided. Bruno Latour (2012), on the other hand, notes how political naivety can turn people skeptical of risks. This prevents people from defending themselves and makes us apathetic towards potential risks. For the context of this study, this means that the broad applicability of 3D/4D printing technology has the potential to make it a very dangerous technology. However, thanks to the widespread benefits of trade, the technology will never be presented as dangerous, and thus there will be no pressure to regulate this technology until the consequences of these risks become impossible through a process of relativisation. The second focus group emphasizes on the scientists' connection to the commercialized market, although the scientists themselves deny as much, instead highlighting the the market's connectedness with academia. They underline the applicability of academic knowledge to the market as well as the market's demand for academic knowledge, which has become a key condition for funding research. In this sense, the developers become economically dependent on market mechanisms because funding is a prerequisite of doing research. It also shows why the hackers from the second group (Group B) are so dedicated to this technology in addition to their daily work.

I am going to revisit a few fundamental paradoxes that I observed when analyzing the empirical data. The first paradox is the lack of a killer application despite the wide use of this technology. The second is the role of a paradox in general, which shows a discontinuity of knowledge and the growing innovation of technical world. The third paradox consists of the increasing innovation of technology in general, which naturally raises the possibility of abuse and has been already mentioned as problem. The fourth paradox lies in the fact that the focus group whose members work with this technology in the most constructive manner fear abuse the most. Now, I am going to clarify the paradoxes, the research of which is generally very beneficial for the development of science.

The power of paradoxes lies in their ability to showcase asymmetries between theory and practice, and they thereby help the development of science in this indirect sense. Such a paradox may be that this kind of a progressive technology does not have a killer application. On one hand, if we consider 4D printing as a killer application for older additive manufacturing technologies, 3D printing, and smart materials, we can already observe a great contribution to various spheres of human activity. On the other hand, if we consider 4D printing technology as something that does not have a killer appliaction yet, there remains a high degree of uncertainty about whether the technology will become more creative or destructive. Maybe the reason that the second group (Group B) is looking at future developments in a dystopian way is because they understand the potential variability in the utilization of the technology, and thus the risks associated with this technology has. In contrast, the view of the first group (Group A) looks rather more through the spectacles of consumers who are eagerly waiting for the latest gadgets. Following the dystopian view of the first group (Group A), I would lean towards Akrich (1992) and her proposal to use the method of "back and forward" to ensure that the technology is tested in practice. This prevents access to this technology. On one hand, it will bring advantages for the market, and secondly it will prevent the misuse of printing illegal weapons at home. This is just one of instance of an advantage that comes with such an "in-script", but we also need to take care of nature, and to understand trajectories that influence the development of technology. Arjun Appadurai (2012) defines trajectories as:

"*the idea that time's arrow inevitably has telos and that telos are to be found all the significant pattern of change, process and history. Modern social science inherits this telos and turns it into a method for the study of humanity.*" (Ibid., 26)

In this context, it is necessary to change the trajectory currently oriented towards economical production processes to another one which helps create the socio-technical environment for this technology that will lead to the exploitation of its potential in full, in addition to having a productive impact on society. We need to encourage developers to work on creating technologies that will make a positive contribution to society and the environment, and also to represent the scientists working with these technologies alongside the technologies themselves in the eyes of society. This can be done by leaning on how the first (Group A) group portrayed the future of 3D/4D printing. We must create a context in which to use this technology in order to prevent abuse in the form of destructive inventions. While preventing erroneous "de-scripting" is something may not be fully possible, it is a gamble that the modern risk society still needs to learn to cope with. It is necessary to take into account the geography of science and the Austrian socio-technical context in which I studied this technology, as these contexts significantly affect how the technology is seen by actors who substantially influence "co-production" (Jasanoff, 2004).

Latour's (1999) concept of black-boxing leads me to speculate that since this technology has a very wide range of application, without a black box it can easily be turned against the users (Latour, 2012). In accordance with the Austrian socio-technical context, it is necessary to establish a way of observing the use of new technologies in practice. It is a difficult but efficient way to effectively build a black-box that meets our specific requirements, which are designed in order to ensure that this technology become productive and not destructive. Memories of the future (or retrospected prospects (Brown and Michael, 2003)) were mentioned by the participants of the first (Group A) focus group, and can be regarded as the memories of a future that will support the use of technology and prevent its abuse. In this sense, it is necessary for politics to adopt the values expressed by members of Group A as their own and to promote them as the right ones. They must not only value the purely economic goals of the companies operating in Austria, but also take into account citizens and the environment. Thus it can be said that 3D/4D printing should use "informative prediction" (Verbeek, 2006) on its road to becoming a technology that will help increase the standard of living for all citizens, and not just focus on the earnings of corporations, as has happened with countless technologies before. This possibly makes Group B afraid. The market has not yet seen a technology of such great potential that can be used by ordinary citizens. This is why potential users should be familiar with what the technology is capable of, and how it is going to be implemented in their everyday lives. The point is to avoid what Walter Lippman (1925) talks about when mentioning a "phantom public". The chance for an informed public to comment will prevent political uncertainty and avoid the debate between scientists and politicians not working together.

These are the barriers that this technology has to overcome in order to be able to properly integrate into the socio-technical reality. We have to be careful with what we wish for, and perhaps also remain careful when constructing the technology in order to avoid unintended consequences that can affect the integration of the technology in practice. Fortunately, it will take at least ten years before the technology can become a real part of production and thus more accessible for public. It is crucial to use this time to look at what contributions the technology can make and to maximize them, just as it is also important to look at what the negative consequences may be and work to prevent them. In this respect, we will also construct the black-box of the technology. The controversy over the name 4D printing is a good example of how we may find ourselves sometimes looking at the wrong script. All the participants who were interviewed criticized this name and pointed out a need to find a better name so that the terminology is not misleading. While criticizing the name of 4D printing, one focus group (Group A) focused on its inaccuracy and deployment, while the second focus group (Group B) focused on the economic objectives that the current name stands for.

The problem lies in the definition of "programmable matter" that Toffoli and Margolus (1991) define as a substance that can adapt to the environment by making use of the properties of atomic bonds and mechanisms. One group (Group A) regarded this as the "God particle" or Higgs' boson, imagined as the smallest nanorobots that can perform almost any task and modify themselves. As the MIT notes about this particle, is can self-assemble into a desired shape, and change the environment, and also create something progressive that can shift humanity forward through using elements that are already in nature in a completely new way. In contrast, the second group (Group B), sees 3D/4D printing and SM/PM as something easily abused, and as something that could be useful for military purposes in creating indestructible weapons similar to the Terminator or Wolverine from X-Men.

Additive manufacturing of programmable matter and smart materials has a very broad field of application. This is where the importance of finding a killer application lies. For every single field, a killer application can be understood as something so completely different that only the future will truly demonstrate what is may be, moving the technology to another level. Hackers essentially agree with the main idea that the technology will be a great contribution to modern society in the future. While the first group (Group A) does not deny the great potential of abuse, the second puts their main emphasis on this potential risk. It should be underlined that in spite of the huge potential that this technology has, only one negative could be enough to overshadow all the positives that the technology can provide.

If the future is filled with the visions of the first group (Group A), the reality of the technology looks bright and benign, but if the future looks like the imagination of the second group (Group B), then violations and abuse will overshadow the advantages of the technology. In this second case, 3D/4D printing will end up banned from use, and in the collective mind of the society, it will hold a place similar to atomic bombs and other such devices. The opinions of both groups were based on reality, thus the views of the both groups are relevant. It is necessary to understand that both options could also coexist together. We have the technology of additive manufacturing that can produce almost everything that has been possible to produce before with a difference only in the production itself: the production will be done by single machine. We can also create more sophisticated shapes, combine different materials, and use smart materials and programmable matter. This has not been possible until now, and once these production efforts move from laboratories to manufacturers and from manufacturers to households, everything we know could be changed. It is necessary to note that 3D/4D printing is not only a technology itself, but also a way of producing other known and unknown technologies, and this is how the participants approached the technology.

The participants considered 3D/4D printing only as means to an end. What matters is what we create with the printer. This is exactly how additive manufacturing with SM and PM should be understood. It should be understood only as a means that one uses for his or her goal or objective. The first group looked at this technology in terms of the goals that they themselves would like to achieve as well as through the benefits that they themselves would want to experience in the future. However, the second (Group B) group were fearful of the potential goals that others might have. What goals, then, can be achieved with this technology?

The first (Group A) group sees this technology as something that will help create a better world, while the second (Group B) group looks at this technology as something profoundly controversial that can bring great risks. Both groups focus largely on the same properties of the technology, such as the ability to create complex materials, bioengineering, and the production of plastic models. In this light, it is made all the more obvious that this technology is only a means to achieve objectives. Today's modern capitalist society creates a situation in which every aspect of human activity is exposed to economic conditions. Thus, as mentioned in the second group[29], 3D/4D printing will not be used in Africa to help ramp up the local economy and prevent famine, will rather remain in Europe and North America where its investors exist. It is one thing for the technology to be used for industry and another thing for it to be used by the military. As discussed in this paper several times, this technology can be very useful for military purposes, and the US army is the main investor in this technology (Fitz-Gerald, 2013). It is no wonder that their investigations are closely guarded. This shows that the concerns of the participants from the second group (Group B), are not as unrealistic as they may have seemed at first sight. Society faces great risks in its efforts to reach economic goals. Thus there is a big chance for society to be exposed to the face of Asimov's (1978) "Frankenstein Complex".

5.3 Distinction between Experts and Hackers

In this summary of the hackers' views, I tried not so much to summarize their attitudes as to use them to supplement the issues the experts could not answer, owing to the hackers' interaction with the technology being vastly different in character from that of the scientists'. I consider this as a complete convergence of the attitudes of all stakeholders and the data that I received from them. In the upcoming chapter, I am going to recapitulate parts of the research that helped me obtain the data that contributed the most to my understanding of certain aspects of this technology. Also, I am going to highlight the discrepancies between the views of the scientists and the hackers. This will enable me to create a theory that will combine data obtained from all participants. Through this, I am going to create a unified of conceptualizing the technology in the Austrian socio-technical context through controversies. So far, I have suggested on multiple occasions how important it is to take into account what kind of controversies are present in the process of the conceptualization of a new technology. In the following section, I am going to stick with this line to illustrate the variability of the future technological developments of 3D/4D printing with smart materials and programmable matter.

The various structural relationships between academia and business, as well as between experts and lay people, have already been discussed. Thus I am not going to deal with these issues now. Instead, I am going to concentrate more on the implications and consequences of

[29] See Chapter 10.5, Hackers, Group B

this part of the reality of a technology in development. By the word consequences, I mean the differences of opinion between the actors when it comes to 3D/4D printing and its future social implications. This will be implicitly indicated in the brief summary of the discussion about the issues brought up by individual actors who took part in this project. After this step, I am going to dive straight into a theory that will reflect their views. This work was written in a manner that the reader can smoothly get to a specific issue. By briefly revisiting all the contributions of individual participants in the research, this allows the reader to recall the crucial considerations were for each participant and group. Before the sum up of the contributions of the individual actors, I am going to hint at the controversies that the participants discussed.

The whole issue of 3D/4D Printing is a highly controversial one because of the wide range of applicability that this technology is associated with as well as the state of the contemporary society, which makes this technology very risky. It is a technology that is unlike anything that has been known before, and it inevitably leads to a mindset-shifting that will complicate the implementation of this technology in society.

Two extremes are possible. Either this technology will inevitably lead to a dramatic rise in pollution due to cheapening production costs, or it will bring about a rapid development in science and technology that will boost the emergence of areas that are without any regulation, similar to what happened with genetic engineering. The experts hold out hope for the proper use of this technology and question[30] the "in-script" along with regulation that does not yet exist. The width of applicability makes this technology very easily exploitable. The possibility of a dystopian or a utopian future go hand in hand. The ´"black box[31]" for this technology has not yet been realized, and it might not ever be. In communications with participants, many were in disagreement about whether this technology should be regulated or not, and whether it is indeed desirable at all. Participants were also divided on the whether this technology has found its killer application. Some argued that the killer application lies in economical production in industry, while other participants argued that a killer application and the breakthrough of the technology are yet to come.

All the participants agreed that the implementation of this technology in industry and society will come about gradually. The wide range of possible uses also carries a wide range of risks, and while this technology can be used to make complicated medical products, it can also be used to produce weapons so sophisticated that we cannot even imagine them yet. Controversies about the technology are best demonstrated through the main language of the technology. 3D/4D printing is defined as a technology that uses "programming", yet the majority

[30] How are conceptualizers of 3D/4D printing imagining the regulation of the technology in the future?
[31] See Chapter 10.1.5, Black- Box(ing)

of our participants strongly disagree with this assessment. The ways in which individual participants imagine the development of the technology relies in part on how they are using it today. Now, I will briefly summarize the individual participants' views and the fundamental insights that they brought to the table.

The main actors in the development of any given technology are scientists. This is why I started my research with them. This expert group consisted of the six scientists/experts from different backgrounds who work with the technology on a daily basis. Their views differed on the basis of their personal fields and interests. In many cases, their opinions matched well. When describing individual scientists and their attitudes, I covered the same controversial points that I will not elaborate on further here, as I would be saying only what has already been said in this work. Instead, I am going to focus on the most important things said by each expert which helped me to formulate my analysis.

The first expert was Dr Scott Benedetti, a polymer chemist who uses additive manufacturing and photopolymerization to produce non-toxic materials for the treatment of complicated fractures. This expert's input was essential for my research for two reasons. Firstly, Dr Benedetti was my informant and thus helped me to contact the other experts. Secondly, he helped me realize some essential features of this technology and thus stimulated my critical senses. According to Dr Benedetti, the most important controversy and issue was outlined by the experts from the MIT in their presentation of the new technology. According to Dr Benedetti, the terminology of 4D printing is only a buzzword designed for attracting investors. Similarly, the term "programmable", according to his judgment, is inaccurate and misleading. He criticized the fact that the expectations attached to the technology are too big, running the risk of its future ending up in parallel with 2D printing, thus risking enormous wastage caused by the cheapening of this technology. He called for inventing a way of self-recycling; a 5^{th} dimension of the printed creature after use. The decomposition of prints and the parallels with 2D printing were also acknowledged by other experts. In the context of regulation, this expert also brought up some control criteria that should be "in-scripted" into this technology. However, he also noted that the regulation of this particular technology will be very complicated.

Dr Emerson Lewko is director of the Institute for Material Science at the technical university of "X" in Vienna, and his primary focus is on additive manufacturing. Dr Lewko criticized the concept formulated by the MIT, as well as the use of the term "programmable". He says that this technology actually makes more us of the laws of nature and biological rules than of programming in the engineering sense. Mindset-shifting, according to him, is a major concern to take into account when introducing any new technology. Freedom brings responsibility. In his opinion, it is not the hardware that is problematic but rather the software, as it offers opportunities for lay people to get instructions for making weapons. However, he was not worried about this regarding 3D/4D printing, as he thinks the technology will remain a hobby outside industrial uses, and that people will not use this technology for anything but printing just for fun. An important point that this expert pointed out dealt with the beneficial promises for industry which the development of this technology brings. Dr Lewko also noted the possibility of storeing designs on computers and manufacturing the product once there is a demand for it, thus doing away with needing to store it. Dr Luce Cuesta offered insights into the commercial utilization of this technology. In this context, he criticized the name 4D printing and some questionable statements made by the experts from the MIT, which he thought to carry the risk of causing unwanted effects in society. His main contribution to my research consisted of confirming my hypothesis about the experts in Austria not being well or completely informed about the terminology introduced by the MIT, as he was the third interviewee in a row who heard this term for the first time.

Dr Kenneth Hyams deals with the development of ceramic materials and photo-curable suspensions in additive manufacturing. Medical uses and the printing of ceramics are important applications of additive manufacturing. His cooperation with various companies and the University of "X" was significant for highlighting the relationship between academia and business. Dr Hyams assumes that this technology will change the way the economy works. He outlined the problems of the industrial misuse of this technology as the production of more efficient weapons, which was keenly taken up by Group B during the focus group part of this research. He also discussed the possibility of producing new shapes and imaginations, as well as mindset-shifting. Dr Hyams sketched out the significant technical challenges of this technology, the most significant of these being that despite the technology's promise, sometimes other processes or ways of manufacturing in certain industries are still more efficient than additive manufacturing.

Ing. Vogele belongs to the group of experts from the business side of the technology, and his greatest contribution were his views on the interdisciplinary collaboration of experts from various fields. In this sense, the technology of 3D/4D printing creates a new kind of a field for new kinds of collaboration. Ing. Vogele's opinion on the technology was very significant because he singled out both potentially productive and destructive uses of the technology. He also followed up on the parallel with 2D printing, and strongly suggested the necessity of focusing on more than just the industrial revolution. In his opinion, we should also focus on the ecological revolution and on saving natural wealth. According to Ing. Vogele, this technology is considered to be the way forward toward the revolution of technology. Thanks to this, Ing. Vogele also offered a critical view about my analysis of the first focus group (Group A).

Dr Sonquist deals with additive manufacturing technology in medical use. He cooperates with academia and industry, which enabled him to offer a critical view on the impact this technology can have on industry in the context of printing steel. He pointed out the mistake of using additive manufacturing technology when there are more efficient methods of production. He also considers manual work in the context of any technology as indispensable. Dr Sonquist takes a very critical stance regarding the continuing technical problems of this technology. One of these problems comes down to the high user demands of the technology, which he considers to be something that is known in STS as "in-script", preventing the use of this technology by lay persons and thus guarding it from misuse by the public.

The hacker focus groups, despite their different overall attitudes, were crucial for the recognition of the coexistence of both the creative and destructive potential of this technology. These participants offered views that sometimes went into extremes, and as such I approach these opinions with some reserve. Nevertheless, the participants brought very interesting opinions to the discussion on what effects the technology can bring to society by virtue of its application. The main benefit of engaging the hackers in my research came in the context of examining the controversies that the scientists had outlined. However, they also brought up some new controversies and significantly supported my research in other ways. I am going to outline the main benefits gleaned from both focus groups.

The participants of the first group (Group A) were individuals in close contact with institutionalized science, which had clearly influenced these participants' views on this technology and prompted them to look at it from a reasonable angle. They saw the benefits of this technology in terms of promoting a better future and a way for mankind to reach a higher level of evolution, which will result in a greener approach to nature and also stimulate the human spirit. They envisioned major contributions in design but also in the production of prototypes, enabling the production of higher quality and more efficient inventions. Although this group did not deny the possible destructive consequences of this technology once put in practice, they saw these as minor issues when compared to the benefits that this technology can bring. This group was most significant for the ways in which they outlined their futuristic look at the technology. Such a presentation of additive manufacturing with smart materials and programmable matter is a good example of how this technology ought to be framed to support its potential of yielding social benefits.

The members of the second focus group (Group B) have distanced themselves from institutionalized science because they consider it too commercialized. In this regard, the participants of this group were closer to hackers in the true sense of the word than the first group. The attitudes of this group were the most controversial in comparison to the other participants in this research. The group feared that if conditions do not change in the manufacturing processes of a risk society (Beck, 1986), this technology may become fatal for humanity. According to this group, although capitalism offers a suitable environment for the development of the technology, it does not think twice about the unintended consequences of applying the technology to practice. This group offered many dystopian scenarios which were described in terms of the fulfillment of economic goals, of exploiting this technology for war causes, and of the destruction of social values and the resulting disintegration of society.

There were many common points in the views of all the participants. However, each participant interpreted these points differently and attached different ideas and values to them. This gave rise to a variety of perspectives on the future of additive manufacturing with smart materials and programmable matter. All the participants agreed that the technology is unquestionably very progressive, and it is going to have a huge impact on various sectors of manufacturing as well as society. The participants also believe that the implementation process will take place gradually. None of the participants were worried about the technology impacting society all of a sudden.

It is important to realize that 3D/4D technology will have a major impact on society. Therefore it is necessary to properly frame it properly. Despite the presence of the destructive potential of this technology, there is no need for anyone to be afraid of it. However, we must certainly approach its development with respect and avoid mistakes from the past.

6 Grounded Theory

Now, I will discuss the most abstract level of the theory I have used to express the conceptualization of the technology based on empirical data, and I am also going to reflect on some general observations about development of additive manufacturing with smart materials and programmable matter in 3D/4D printing. Grounded theory offers the tools for summing up how the technology is used today and what possible directions the development of this technology could take in the future.

The relationship between the development of the Austrian society and the development of this technology should be monitored so that we can better understand the potential consequences of the introduction of this technology into everyday reality. In this section, the attitudes of individual participants will not be re-addressed. Rather, I will focus on how this technology is conceptualized in general.

During the data interpretation process, I will adhere to a narrative structure which allows me to graphically interpret the empirical data. I will start by how the technology is used today and what the actual benefits that this technology offers to society are. In relation to this, the role of mindset-shifting caused by the wrong choice of name given to this technology by the MIT scientists should be noted. The applicability of this technology is very wide, as shown by the array of uses that my participants mentioned. While this indicates a promising future in terms of the economic benefits of the technology, it also seems to form a parallel to the development of 2D printing. This parallel is going to allow me to interpret the current direction of 3D/4D printing. I am going to use the utopian and dystopian angles of looking at the possible future developments of this technology. It is necessary to bear in mind that these two aspects of possible developments influence each other. This allows me to seamlessly switch to the potential black-boxing of this technology and to discuss how it could be and should be properly regulated. This chapter is going to be completed with a discussion of the most disturbing controversies that accompany the technology of 3D/4D printing, and I am going offer a summary of the integrity of the technology in society and its conceptualization in terms of the actors who work with additive manufacturing on a daily basis.

Additive manufacturing has become a trend in recent times, and every day we hear from the media about new applications for its use. This trend is, however, likely to cause this technology to be used for purposes that could be better met by other modes of production. The emergence of 3D printers dates back to the eighties, and the emergence of 4D printers only to 2014. In spite of the fact that additive manufacturing technology has come a long way, it still has significant technical limitations. Among the most serious of these limitations is the slow acting and repeatability problem. However, both of these limitations are being addressed every day by researchers seeking to fix the issues. The most serious problem of using this technology might well be considered high user demands, whether these demands are directly connected to the operating of the equipment or the need to store the material for printing. These problems will eventually certainly be solved. Another thing we need to consider is the fact that even if these technical limitations are overcome, is it still possible that some manufacturing processes will remain untouched by this technology. An example of a production process that cannot be replaced by additive manufacturing is manual work, as people will still pay for hand-made products (e.g. a Rolls Royce*).*

The MIT declares that 4D is a new printing technology in the domain of which prints can keep evolving over time. This is very misleading due to the fact that this technology is not as new as proclaimed, and certainly not as omnipotent as it has been made to seem. 3D/4D printing is just an evolutionary higher level of additive manufacturing. It is possible that the chosen terminology of "4D printing" will never be acknowledged or used in Austria due to its uncertainties. It would be much more accurate to call the technology "additive manufacturing of smart materials", although it must be noted that the name "4D" is very catchy and sounds better than "additive manufacturing of smart materials" from a marketing point of view. The pragmatic reasons for the MIT experts to create the halo effect are obvious, and will probably help amass more resources and investments for their research. This technology is also declared "programmable". This is to point out that, without the use of microprocessor and mechanical parts, a "print" can respond to an external stimulus. This, however, does not constitute programming in the strict sense that we understand computer programming and coding, but rather refers to a sophisticated use of the chemical and physical properties of these materials. Names play a key role in the conceptualization of technology in society. Mislabeling this technology as 4D can give rise to extreme and unrealistic expectations. .

Additive manufacturing is still a complementary technology to other technologies in the sense that itself cannot yet completely replace traditional methods of production. It is suited for producing prototypes, but for mass production it is still much too slow and expensive. Another thing to bear in mind is that although the technology is capable of producing mechanical parts, without additional reworking it is useless. These are problems that can subsequently be addressed in later 3D printers, allowing them to print color models and increasing accuracy.

3D/4D printing is not only a technology but also a means to produce other technologies. The key to successfully conceptualizing the technology is mapping out the potential purposes for which it will be used. 3D/4D printers are a technology enjoys increasing popularity across a range of disciplines, and its applicability is very broad. This trend will undoubtedly continue.

However, it is essential to predict what political and economic goals will become important behind the scenes of the development of this technology.

This research showed that scientists are not economically independent, and that they are either directly or indirectly dependent on market mechanisms. The link between industry and academia, in the context of conceptualization and implementation of this technology, is essential to keep in mind.

Scientists are trying to invent what the market demands and, in turn, businesses lobby academia to produce new technologies that can help maximize profits. This technology will have a huge impact on industry, and will eventually lead the way to the restructuring of the market and industry. However, it will not harm the market. The commercial sphere will use the benefits of this technology to the highest extent possible. The conceptualization of this technology will be a crucial factor in the forming of the public opinion. This is the reason why the scientists at MIT named this technology as they did, trying to idealize the technology and highlight its wide practical applicability.

Additive manufacturing has a very wide range of applications, making it a technology with great creative as well as destructive potential. Industry will benefit from the technology more and more in the near future, which will also put pressure on scientists to promote this technology more idealistically than negatively to avoid concerns about the risks associated with potential misuse. The market benefits of this technology lie in cutting production costs to a minimum. Another obvious benefit is the saving of production materials, as additive manufacturing only uses the precise amount of materials that are essential for the final product. On average, a 3D printer uses only one tenth of the material that subtractive manufacturing would use in production of the same product.

One of the spheres of possible application for this technology is gene-printing. Through this, bio-technology can be developed in an environmentally friendly way to produce various substances. It is also possible that this technology could have a major impact on genetic engineering, an area that was almost unimaginable a hundred years ago and still deals with major mindset-shifting. The technology is becoming more powerful. People are at a loss for answers on how to regulate such technology. This may, consequently, bring about a lot of controversy. Some of the controversial issues surrounding the introduction of this technology may also consist of whether this technology ought to be used in setting where it would replace a number of workers and cause them to lose their jobs. 3D/4D printing is a technology that can have a huge impact on society, and this potential conceals a number of risks. Risks associated with the development of scientific and technical progress are a part of modern civilization. This technology, however, due to its wide range of application, may help industry to develop to a higher level in a way resulting in a number unanswered questions. This makes the technology potentially very dangerous. This fact can be understood by looking at the US army, who are the largest investor in 4D printing. This makes it possible for this technology to create a real Frankenstein. Additive manufacturing of smart materials can be considered as impossible to black-box, given the difficulty of ensuring that this technology must never be able to, for example, print weapons. Any legal regulation could jeopardize developer activity. Thus it is necessary to create a social image of this technology that will lead to the development of its creative potential. It must be possible to create a cult in society that will idealize the technology and thus create a social environment that is against abusing this technology. Although abuse cannot be fully avoided, this environment could help create the conditions under which abuses will be viewed as insignificant when compared to the overall benefits. Another aspect of regulation is ecology. The regulation of the quantity of production and the pressure to produce recyclable products play a crucial role. Hence the need to develop a so-called fifth dimension will grow even stronger. The point of this is to manage the materials after the fulfillment of their pre-programmed function so that they can fold back to their original state or completely decompose.

This technology is very controversial. On the one hand, it is a technology for the production of further technology. On the other hand, this technology has not yet found its killer application.

The most ideal killer application for this technology would involve a fifth dimension, which would be capable of producing disposable products that would not burden the environment. The controversial aspect of such a technology is that ordinary people have no clue about what it is. Thus it faces the challenges of significant mindset-shifting. Since its penetration into everyday practice will be gradual, the framing of this technology needs to be made precise in order to fully exploit its potential and prevent abuse. It is necessary to start creating memories of the future that make this technology into one that will lead to a better tomorrow.

7 Methodological Reflection

Now, I am going to supplement the grounded theory of the previous chapter with the criteria provided by Straus and Corbin (1990). I am also going to evaluate the analysis. I will use auxiliary criteria that other authors have suggested so that I can evaluate my research efforts from different angles. I consider it important to offer the reader an opportunity to evaluate the objectivity of the claims made in this research, and to examine the accuracy of the analysis of the empirical data. Since I have tried to analyze the data conscientiously, I do believe in the accuracy of my analysis of the research and the results obtained. In reference to Popper (1995) and his idea of falsification as a condition of good science, it is necessary to outline the possible mistakes I may have included in the theory created in order to be able falsify my results. This will also be beneficial for further research and the co-production of society and additive manufacturing. Popper points out three bases of qualitative research: precision, consistency, and relevance. I tried to build on these principles while working.

When collecting data, I tried to implement all the methodologies outlined in the previous chapters. I also analyzed the data continuously, which allowed me to increase my Theoretical Sensitivity[32]. However, the basis of the analysis was formed by the computer, which significantly affected the course of my research efforts. The computer provided me with a complete treatment of the data as an analysis of deviant cases. For instance, after collecting the first data with Dr Benedetti, I created an analytical scheme which I used during additional data collection so that I could draw a small set of applicable rules by which I could clarify concepts, note discrepancies, and dissect data. This was done in connection to Mehan (1979) and his theory of analyzing deviant cases. Atlas.ti allows for the possibility of interactive work with codes as well as for re-coding and redefining relationships between categories, which helped this analysis greatly.

In outlining the methodology of qualitative research and the creation of grounded theory, I mentioned the main steps of the analysis. While interpreting the data, I took care to distinguish the participants' attitudes and interpretations by using the theoretical concepts of STS. I also explained the influence of literature on the creation of a theory, which was reflected in interpreting the data. Now, I am going to briefly outline the process of doing analysis by using the Atlas.ti software. As I said, I used the program for processing sociological concepts from the STS field, though I could not include all of it as a single hermeneutical unit, as the work would be very difficult for the hardware because of the volume of data the computer would have to process. That is why I chose the most relevant works out of which I created a copy bundle (a tool from Atlas.ti) containing the original text of the hyperlinks and codes.

These parts of the copy bundle were imported into a hermeneutical research unit. In this way, I had easy access to the concepts and I could easily connect them with the empirical data. The following sections outline the analysis of the empirical data in this program.

Notes from the research diary were rewritten in the software program in the form of memo notes. The memo notes used by Strauss and Corbin (1990) are what Disman (1993) defines as a dialogue with one's self, and I chose to split mine into four levels. The first notes were only provisional, and they originated during data collection and helped me to encode data.

[32] See Chapter 10.2, Theoretical Sensitivity

The second level were remarks that described partial analytical tasks and the problems that I faced during the analysis, mainly involving technical problems. Thanks to the listing of the technical problems, I was able to additionally solve them and to correct errors, which this enhanced the practical quality of working with the data.

The third level entries were entries noting the formation of theories in the shape of recorded thought processes. These memo notes were each assigned to a code to which they related. The fourth level were built from comments that depicted causal relationships and allowed me to quickly recall what was going on in a particular case. This level was written after the completion of the various stages of research. Thanks to these remarks, I was able to maintain a preview of the work and to become familiar with inconsistencies in data analysis. This was caused by the fact that during the research I realized that some of my chosen methods worked better than others, yet I needed to record the original data to understand which processes proved impractical. It was important for me to discover even the procedures that were impractical, as well as to maintain the flexibility of working that supported creativity.

The recording charts were not only in the form of memo notes, but also consisted of comments on codes, relationships between categories, and network representations that depicted the relationships between codes. Thanks to these, I had the opportunity to work with well-defined categories that gradually became better and better defined. The codes were divided into three levels according to the panel stage analysis conducted when they incur. Thus they were divided according to whether they were made during the open, axial, or selective coding stage of analysis. They were transferred further, creating a distinction between levels of particular categories. To link these levels, I used a special network view which captured the relation between the codes at different levels. In the virtual version, it seemed that the first level are hyperlinks within the audio, audio-visual records, or text records of empirical data. Each excerpt was assigned open codes. Axial codes and selective codes were also added to the originally created snippets. In doing so, I rewrote comments of extracts, but the comments of codes remained unchanged for me to keep track of why I originally attached the various codes to individual snippets. Thanks to this, I assured consistency in the work, which allowed me to create a theory and also to keep track of how I came to conclusions during the process. The procedures of the creation of theories were recorded in the form of memo notes. In this way, I applied to the data "Web view", (Atlas.ti), which assisted me in keeping track of the work that had already been accomplished.

In practice, this looked as follows. Before any data collection, I was determined to figure out what I wanted to observe, and I created the main and supplementary questions. During the interviews and focus groups, I tried to structure the interviews to not only answer my questions but to help the participants keep the focus on the research objectives, to be used more like a crutch in an emergency. The questions fulfilled their role in analyzing the data and this also ensured that during the data collection, I would not miss anything essential. During the data collection, I wrote short notes on paper, which I later used to start the process of open coding. After importing the data into the software program Atlas.ti by using hyperlinks, I indicated a link between individual statements and allocated the open codes that should capture the uniqueness of the expressions that participants used. Thus if a participant used an interesting expression, I used it in turn as InVivo code. However, if I found a better or more general term, I used the code-name accordingly.

When I noticed a category that was merging more of these specific codes, I assigned to it all the relevant snippets or quotes. I repeated this process every time when new data collection occurred, but also in the case of all previous records, empirical data, and transcripts. Simultaneously with this process, I created a network display for snippets and quotes (Atlas.ti), which enabled me to create a mind map of the statements of the participants. I also created a network view specifically for codes and for linking codes and extracts in particular. I commented on these network maps with codes and snippets. An important aspect of this activity was to observe the extent of the view, which enabled me to ensure the validity of evaluating the frequency of individual codes. Although I did this sometimes intuitively, a crucial guidance tool was the code coo currents table tool that allowed me to quantitatively evaluate incidences of individual codes. This allowed me to detect deviant cases and to implement them into the narrative skeleton (Strauss and Corbin, 1990).

The recasting of questions before the research allowed me to identify the focus of the questions during the analysis of the data. This allowed me to create in vitro codes that are more or less unified. The unifying of these codes allowed me to make use of an useful tool to quantify the responses, which turned the codes into more credible criteria for examining different aspects of context.

This way of working was only an addition, and I have not seen it done anywhere else. This is why I consider it important enough to mention. These codes allowed me to keep the empirical data ordered and controlled. Their main goal was to identify general categories in transition from open to axial coding. Their contribution was indispensable in the creation of selective coding. This means that before starting the selective coding, every extract was assigned at least three codes, although I tried to keep the number as low as possible to maintain the practicality of workflow. Nevertheless, the maximum number of codes assigned to one passage was 44. However, I also had snippets that did not get assigned one single code. These were short excerpts that did not have a meaning by themselves, but rather expanded on another passage. The total number of codes reached was 513, and was divided into 83 families. Because of such a large amount of data, it was essential to work also with in vitro codes. These codes had 1701 links which created a dense network of real importance. Network maps were essential for maintaining a clear view of the work. These figures are for the total number of codes at work. The number of selective codes was 104, and these were divided into 21 families. In these numbers, I do not count the conceptual codes that were assigned to the passages. While these numbers do not say much on the formation of theories, they say enough about the amount of information with which I had to work.

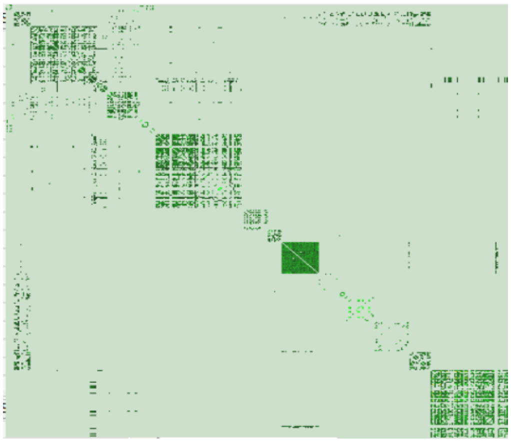

Figure 1.5 Code Co-Occurrence Table

Selective coding began to take place after I chose a central category, which I mentioned when describing the methodology of analyzing data before the interpretation phase. Controversies affect the conceptualization of this technology through their influence on the institutionalized and un-institutionalized actors. These roles originated as super-codes, which were codes that were created on the basis of pre-defined logical relationships between the codes that incurred earlier. Most of them were made up of the traditional way of passing data and marking passages with relevant codes. In this work, it helped me a lot to network maps that interlinked codes and snippets. Based on selective codes, I created network maps that organized snippets into a logical structure through which the data were interpreted. By the practices that I describe here, I tried to create a theory that was actually grounded in data. Before I ventured into the work of writing the whole hermeneutical unit. I checked the data several times. When controlling the hermeneutical unit, I focused on the relationships between participants which I had overlooked, as well as the relationships I first put importance on, but at the end the relationships that proved to be negligible ended up being cut out.

The virtual environment was very useful as a means of conducting the analysis because, in addition to allowing for greater interactivity while working with data compared to empirical paper work, data can be modified and it is possible to simply overwrite it, and a change automatically manifests itself in the hermeneutic unit.

7 Methodological Reflection

Above, I briefly outlined the progress of the work that I have used to carry out an empirical analysis. Now, I will get directly to the evaluation criteria for research. For me, the most important evaluation criteria for research are practical criteria that are described by Straus and Corbin (1990), which I tried to keep in mind throughout the whole research project. That is why I tried to categorize as well as conceptualize, and why I have the analysis grounded in data.

I watched closely for correlations between individual codes, which allowed me to define the links between them and also to avoid vague statements (Strauss and Corbin, 1990) about the relationships that exist between individual categories.

A suitably chosen central category enabled me to stimulate a theoretical density that offered a convenient frame for the integration of all categories. To me, the influence of controversy on the conceptualization of the technology by the actors dealing with it seems to have clear impact. However, I leave the reader to assess this. Theoretical saturation is demonstrated by the descriptions of individual participants. The claims in the data are repeated, and because I engaged with a wide range of relevant participants it is possible to assume that in the Austrian context there are no other data. Discussing the procedure how I processed the data from the beginning of the study to the end gives the reader an opportunity to assess the correctness of the procedure I chose as well as the findings made.

Hammersley (1990) defines validity as a condition for the research to really represents social reality as it is. The same author defines reliability as the degree of consistency when the same phenomenon is identified in the same way by different actors. These two criteria are indeed originally from quantitative research, but Silverman (2011) justifies their applicability in qualitative research, as it is essential for any methods and conclusions to be reliable and valid. Political objectives are not enough for reflecting social reality, and it can easily happen that the right side will be the one who shout louder. I have explained in this work two aspects of the research.

Now, I will point them out briefly. There are various methodologies for the collection and analysis of data that are recognized and respected in academia, and that are relevant for examining social reality. I consider these to sufficiently demonstrate the reliability of my research. The grounded theory method of research is also a scientifically relevant way of researching reality. The way I grounded my statements in the data established the validity of this work. I will not explicitly address these two criteria of reliability and validity, but rather outline the criteria relating to the applicability of the research in practice.

Charmaz (2006) lists the four criteria for assessing research that I consider very relevant for evaluating my research efforts. These terms are credibility, originality, usefulness, and resonance. While I tried to focus mainly on the last of these criteria, my research can be considered credible for the same reasons it can be considered relevant. I used the methods of expert interviews, focus groups, and the GTM, which are well respected in the scientific community. While studying relevant literature on the subject of my research, I did not come across sociological or STS-related research which dealt with the same issues. This is why I consider my work original. This also caused some difficulties in the interpretation of data, which is why I had to interpret them through the use of either general STS concepts or through the statements of my participants.

I have attempted to write a research report with a focus on the STS field where I tried to conclude the results of my research in a manner which would allow STS researches to identify with the conclusions. Thus I think the criterion of resonance given by Charmaz (2006) is fulfilled. As I mentioned already, the criterion of usefulness was very important for my research. I tried to formulate the research and the conclusion in a way that is going to allow other students to follow up on the issues that I have outlined. I also tried to point out the seriousness of the lack of black-boxing, which could be an inspiration for politicians to exploit the potential of the additive manufacturing technology in a way that could benefit every citizen of Austria.

These criteria mentioned earlier consist of closely related aspects of research, and I consider them appropriate criteria for the evaluation of the research. With this paragraph, I end my discussion on the interpretation of the data, and hope that the systematically interpreted empirical data has enabled the reader to fully understand the issue of 4D Printing in the Austrian sociotechnical context. Respectively, I hope that I fully illustrated the way in which this technology is conceptualized in Austria.

8 Conclusions

Now I am going to summarize the essential aspects of the technology of " 4D printing". Firstly, I will outline the complexity of the socio-technical controversies that this technology brings. After this, I will gradually untangle the linguistic controversies, the issues relating to the regulation of this technology, the possibilities of potential abuse, and attempt to answer the questions of why we can talk about these innovations as the beginning of the third industrial revolution, why we can consider a 3D/4D printer as a new non-human agent, and in what sense it can become a part of the household.

Let us go back to the birth of additive manufacturing, which has influenced industry and design to such great a degree. Shortly after introducing the technology to the market, scientists and conceptualizers started to talk about a new revolution in design, and some of them even took to dubbing it the "third industrial revolution" (Rifkin, 2011). The technology brings new possibilities for companies to become independent in research by making use of the benefits of

3D printing, thus removing the need of dealing with suppliers and the transportation of spare parts for the desired product. Access to prototypes is easier than ever before.

The terminology of "4D printing" establishes, as demonstrated in this research, several controversies. When comparing the attitudes of the scientists from the MIT to those of the experts interviewed in this work, The problematics of terminologies like "4D" and "programming"(Tibbits, 2013) were raised numerous times alongside questions about the actual and also different understanding of what the capacities of the technology thus named. This project reveals and discusses a dichotomy of opinions between experts and hackers situated in Austria.

Both the interviews with the experts and the focus groups with the hackers have illustrated the comparisons and contrasts between institutionalized and un-institutionalized actors in Austria. Through this, my investigation has involved scientists, businessmen, and hackers alike, as they are currently the key actors in the field of 4D printing, as the broader lay public still requires a certain degree of "mindset.shifting"[33] in order to truly embrace the technology.

The current mindset in society is influenced mainly by people who do not fully realize the advantages of additive manufacturing, since it has only been introduced to society lately and subtractive manufacturing still works well and is beneficial for many corporations. However, a huge gap exists between theory and practice. The present mindset of society is to a certain extent also sustained by potential future threats to the technology. In this view, while the technology brings countless advancements and creates new applications in numerous fields with exponentially growing benefits, there are also possible violations that might even be outside of the imagination of an ordinary human. In this master's thesis, I investigated how the chosen actors imagine the conceptualization of the technology of 4D printing in the future with specific regard to possible regulatory measures set in place before the technology completely penetrates everyday reality.

3D/4D printing is not only a technology on its own, its main importance lies in creating other technologies. This is why regulation is impossible, as any effort of imposing rules on the technology itself would be similar to regulating the use of hands, seeing as we could use them to kill someone. In the context of this research, it has been pointed out by the majority of the participants that the regulation of additive manufacturing in combination with SM and PM is not really possible, as well as not desired at all. The technology of 3D/4D printing has too broad a spectrum of applications, and if fallaciously defined and handled, the regulation of the technology can harm research and the market as well as society and nature. The participants of

[33] See Chapter 10.1.10, "Mindset-shifting"

this project have thought of this technology mainly in the terms of it bringing about the third industrial revolution, which can change the ways and trajectories of industry on a fundamental level. However, even in this context, there was some degree of disagreement between the participants. The experts and one half of the group of hackers see this technology and its influence as something that is going to lead to societal benefits and advancements, as well as prosperity and the beginning of what has been named the third industrial revolution by Rifkin , 2011). Even when the second group came to agree regarding the advantages of the technology, they strongly pointed out that the development of science and technology in the field of additive manufacturing and its implementation of SM and PM could be easily twisted against society. The question that arises here is how the technology can be "in-scripted" in reality by scientists, and later de-scripted by lay people.

The experts who were interviewed are engaged in exploring the potential of the technology mainly through incorporating new applications of use, while hackers use the technology mainly for personal interests. The current use of additive manufacturing by hackers may show how society is eventually going to use the technology once it is more readily available. The basis of how the technology operates lies the possibility of transporting binary code into the physical world, and vice versa, in order to transmit a 3D creation into binary code by using a special scanner. On one hand, this establishes ground for the creation of anything, anywhere. However, on the other side hand lies the issue of plagiarism and the production of weapons by random citizens, which is more and more problematic with the recent rise in terrorism.

Now, I am going to sketch out the basic ways in which technology affects society. These strands will be clarified by inserting quotes from the experts regarding research done by companies in an Austrian (and generally European) sociotechnical context.

The researchers from the ''self-assembly lab'' at the MIT are convenient subjects for observing the conceptualization of so-called 4D printing. This is because they were not only the first actors in the field who introduced such a technology to the world, but they were also the ones who came up with the term "4D printing". This leads me to the first bullet point of the conclusion.

8.1 Language Controversies

Every regulation begins with language. This is because when we start to call something by a certain name, we are already conceptualizing it (Engelhardt and Caplan, 1987). The linguistic controversy was one of the most central factors affecting my research. The importance of the linguistic controversy is based on the fact that, on one hand, society does not know what "4D" means and what it can it used for. On the other hand, the way in which the scientists from the MIT are trying to conceptualize this technology is misleading. Other controversies arise from these linguistic ones. For instance, the simple vagueness of 4D printing makes it a technology that, if incorrectly conceptualized, can help meet political objectives that will have a negative impact on society.

Even if the scientists from the self assembly lab at the MIT introduce 4D printers as a technology capable of using natural laws and chemical conditions similar to what is known about proteins programmed directly into materials, and if the technology becomes capable of self-assembly, which would enable it to react to external stimuli or a chosen environment, the terms "programmable" and "self-assembled" remain controversial. They have become the topic of critique for the participants interviewed in this project. The core language issue is already the name on its own: "4D". This is because while the term is used in presentations about the technology, the experts and the hackers all agree that the use of a notion of a 4th dimension is not exact, and the term is misleading. According to the interviewed experts, the technology itself is not as new as scientists try to present it as, and it has the same capacities as other technologies do. How the technology works has various interpretations throughout this research. The crucial aspect of this controversy and language issue is the fact that scientists are simply trying to find something that already occurs in nature and continue on to replicate the working mechanisms observed. Even if scientists are the ones who find and invent the technology, many times they do not have a real impact on how technologies are used. We could mention endless instances where this has happened throughout history. One of the hackers commented on the use of the particular terminology of 4D Printing in the context of economic goals in these words:

"*Those who think that in five or ten years we will have all 3D printer at home is in my opinion a bit naive utopianism or communism that we will all have a everything same. Although it would be nice, but it's never like this with anything because in reality society is build on hierarchies and for people from corporate environments suits that the technology slowly dwindle and they may sell printers for half a million, but again that price is not completely inflated, since research and cost a lot of money. Development is the most expensive but I'm talking also about series production, which of poor quality and reduces the cost compared to the minimum selling price. However research would turn itself inefficient, so it is obvious that the developers hold the know-how.*"

An important part of the framing and critique of the terminology lies in the misunderstanding that occurs at the end of the official promotional video of Skylar Tibbits (2013) where, after watching the video, the interviewed participants do not agree with the chosen terminology of the scientists from MIT's self assembly lab, and found the video to be more akin to intentional promotion for marketing purposes than anything else. A majority of the interviewed experts and the hackers saw and understood the chosen strategy for naming the technology, and they believe in the good intentions of the scientists involved in the development of the technology. My criticism is built mainly around the fact that even though I am sure that the MIT is developing the technology of 4D printing with the best of intentions, they have no influence on how the technology will be used in reality, which has already proven a risky gamble in history with regard to numerous technologies. In this sense, many scientists do not see abusing technologies for political or military aims as something they can fight against, but as a bitter pill to swallow.

Another linguistic controversy is the term "programmable". The MIT explains the technology of 4D printing as the printing of materials whose actions are "pre-programmed" on a computer, or where they pu programming is directly embedded in materials. However, this is not completely true. Strictly speaking, this is not programming in the of writing an input on the computer receiving an exact output.

"*But programming in this biological sense mean, that you somehow push the thing to get them to wanted directions but you can't really tell completely the results. There will always will be a variety of results, like all of us look different, also we are the same types of beings but, when you get children you can never [...] where in engineering it means that you'll get yourself early to the point you want if you do the things right. And that's the thing about 4D printing, if the programming will go more to the biology directions, the things will become more fuzzy and if it will be purely engineering approach, things won't get that complex but usually they will become more specific*."

These points that are mentioned in the context of language controversies by Dr Lewko are essential in influencing the future of industry. Once the killer application for the technology is developed and the technology is implemented in industry, it is quite possible that the terminology will be changed again to something that will be more exact in defining the real capacities of the technology, something which will garner respect among all actors involved in the development process. This is similar to what happened with the terminology of 3D printing. In its infancy, the technology was first called "fuse deposition modeling" among other names, and it was only after some time and negotiations that the term 3D printing was established. Language is an essential actor that influences how a technology will be used. We must not underestimate how "4D" printing is presented to society, because this process in turn influences how the technology will or not will be used at the end of the day. This can be understood as a co-production (Jasanoff, 2004) of the name of the technology, of its industry, and of itsdomestic applications.

8.2 Regulation: Positive, Negative

3D/4D Printing is not only a technology itself but rather a production method of other technologies. This means that the regulation of this technology is not really possible in a sense that it may be intuitively understood. The interviews data makes it clear that the regulation of this technology is not possible and, according to the overwhelming majority of the participants' opinions, also not desirable. The technology of 3D/4D printing has too wide of a field of application and incorrectly defined regulations of this technology can harm scientific research, society, and nature alike. My participants viewed the technology mainly through the frame of a new industrial revolution, and they conceptualized it as a technology that can change the methods of production as well as influence the operation of the market. Regarding this question, participants disagreed when imagining the consequences of implementing additive manufacturing into the machinery of the new industrial revolution. Experts, together with some hackers, saw this technology and its impact on production as something leading toward prosperity. Nevertheless, even if members of the second group of hackers (Group B) agreed with this way of conceptualizing the technology, they pointed out that such an extreme and fast development in science and technology could easily turn against the user.

The technology of additive manufacturing with smart materials and programmable matter brings a wide range of applications, and it is very difficult to imagine a functional regulatory framework for the practices and processes involved. This is why we need to ask many questions before this technology is introduced into the everyday world. The most important questions to answer are how we can avoid both waste and the abuse of 3D/4D printing. To answer this question, it is important to realize that this technology interferes with the functioning of the "old world", whether through market mechanisms, democratizing the market, or through the possibilities of creating shapes that no one has ever seen before. This technology has much too broad a scope of application to allow it to be effectively regulated. According to the participants, the in-script of the technology should be concentrated mainly on creating a suitable social awareness about 3D/4D printing.

Regarding the impact of the technology in terms of market transformation, it is necessary to determine the extent to which the admissible transformation is convenient as well as the extent to which old methods of production are more efficient. It is important that the additive production method is not used where other methods of production remain more efficient. The main component of the regulation of this technology ought to focus on merging the environmental and economic benefits of this technology. This would reduce the production costs, and thus further protect the environment instead of simply increasing profits. There must surely exist something like a "fifth dimension" which will take care of "prints" by allowing them to be folded back and recycled before this technology becomes an everyday technology.

8 Conclusions

Since 3D printers can be constructed more and more cheaply every day, they raise the risk of abuse. However, such a risk is negligible in comparison to the benefits that this technology can bring. Since Austria is very careful with new technologies, this setting creates an appropriate socio-technical environment for the potential of this technology to be used to its full advantage. However, it will be necessary to gradually begin forming effective regulation.

8.3 Description and Violation

As mentioned, a problematic regulation scheme can make additive manufacturing very vulnerable. The wide applicability of 3D/4D printing naturally results in the technology being used for war purposes. This means that the products of this technology can be easily used for destructive purposes. The technology, in the case of failure in black-boxing, can act as a damaging factor. It may bring about the disintegration of society and a sharp rise in unemployment, creating a super soldier or various ways of environmental contamination.

The framing of this technology today is still very austere, as it is still influenced by a lack of a killer application. It remains unclear what the killer application for 3D/4D printing could be. A society may find itself face to face with the "Frankenstein Complex" (Asimov, 1978), which will be very difficult to cope with. This technology has a very large contribution potential with regard to business, and it is most likely that corporations will control the future development of the technology. While this is largely referred to as an environmental impact, the emergence of super weapons is not so unrealistic. This is based on the fact that today the US army is one of the most significant investors in this technology (Fitz-Gerald, 2013), and there are also companies in the US that are already using additive manufacturing to produce more efficient firearms.

A very problematic aspect of this technology is its potential to bridge the digital world and 3D or 4D objects. This makes it possible for almost anyone who is able to handle this technology at home to download to their computer models of weapons and print them at home. Another very important issue of the digital aspect is plagiarism. This is not only about free home printing of 3D models, but also theft and the abuse of data and inventions. These stealing of 3D models can be an issue with both consumers and producers, but also between the producers themselves. As we can see, this technology comes not just with new possibilities of use, but also with numerous potential risks.

8.4 Negative Regulation

Although the technology is very easy to abuse and its regulation is not possible yet, it is questionable if any regulation is necessary in the first place. The market will be a key player in the development of 3D/4D printing. However, the market is able to regulate itself, much like the academic world.

A fear of this technology does not exist. Although the technology offers numerous possibilities for abuse, its potential abuse will be negligible in comparison to its usefulness elsewhere. Regulation of domestic printing is not needed yet because few others apart from experts are able to meet the high user demands. As for the printing of weapons, there is no way of focusing regulation in a way which would separate the production of weapons from the production of other objects. At the moment, the only hope lies in the self-regulating characteristics of the market.

This technology still has not found its killer application, and excessive regulation could prevent its emergence. While it is necessary to create an appropriate socio-technical framework for this technology as well as to focus on environmental regulation, over-regulation can easily freeze the research, as has been mentioned by all the experts in this project. It is important to remember that science needs to work freely, and at the moment any regulation in this area could be very harmful to the development of this technology. While regulation can indeed provide an appropriate framework for the development of a technology, it can also completely prevent development.

In words of *Dr Scott Benedetti*:

"*I see the future of regulation of additive manufacturing in regulation of commercial printers , so basically the designers of commercial printers would inscribe some stuff which will be not possible to do with these printers and also law would make a straight regulation for the public so potential hacks would be punished if printers would be abused*."

8.5 Third Industrial Revolution

The benefits and uses for additive manufacturing and smart materials lie mainly in industry. One of the biggest advantages is its ability to print different kinds and combinations of materials. This reduces the need to import and keep spare parts in stock, which is one of the biggest factors that increases the final price of goods. On the other hand, this technology also raises the possibility of cooperation for experts from several disciplines, thanks to the ability of this technology to produce products consisting of multiple materials. The individuals who participated in this project foresee a gradual penetration of this technology into the market in the form of production services. In the context of economic goals, the participants do not see this technology as something that will threaten trade, although they imagine rather different possible futures. The market will benefit from the technology. In practice, this would translate into 3D/4D products gradually replacing subtractive products while nobody will really be bothered about how things are made. Customers want a product that is inexpensive and reliable, and manufacturers want to sell a product that has as low a production cost as possible. Although these and other economic conventions should remain preserved, the market will gradually change after the arrival of the killer application for 3D and 4D printing. Dr Lewko illustrates the complexity of this in a single sentence:

"*So the material is the key to making things different.*'"

Rifkin's "Third Industrial Revolution" (2011) describes additive manufacturing as a technology that has an impact on the democratization of human production, that accelerates innovation, and that reduces the cost of logistics and saves energy. To summarize these ideas of 3D/4D printing and its applicability to industry, Rifkin's "Third Industrial Revolution" functions much like Melluci's (1996) memory of the future. This technology is one designated for the purposes of business (Mitcham, 1994). Through the production possibilities offered by 3D/4D printing technology, it can affect the development of prior technologies and improve them, as well as facilitate an easier production of prototypes. We see how this technology can influence the market as we know it.

8.6 New Non-Human Agent

Firstly, it should be noted what smart materials are. They are technical artifacts that can change shape through physical-chemical relationships. Designers use these substances to create something completely new, and they try to implement these materials in industry through engineering. Smart materials are usually associated with nanotechnology and quantum mechanics (Toffoli and Margolus, 1991). Researchers from the MIT, the ones who first labelled additive manufacturing with smart materials as 4D printing, stand in a prime position to affect the initial conceptualization of the technology. Through their choices of expression, they are influencing not just national but also global sociotechnical imaginaries (Jasanoff, 2004). Skylar Tibbits and his colleagues talk about 4D printing in terms of the programmable capabilities of 3D printed materials, which gives new possibilities to mankind. What they do not talk about is the progression of technology going hand in hand with the possibility of risk (Beck, 1986). The scientists from the MIT focus on a few features of this technology, which I am going to express through their words. In the context of these facts, their words indicate the size of the possible impact that 3D/4D printing can have.

"*We make machines that make things; we're integrated into that theme. We're arguing that people can collaborate with materials and materials can be collaborative. It's not just us making stuff and forcing materials into place, it's making materials themselves.*" ." (Tibbits, 2014, Interview with Paul Wallbank, Personall Interview, Sydney , April , 30 , 2014).

The technology of 3D/4D printing is an entirely new kind of a "non-human" agent with its own specific characteristics which is gradually becoming part of the production processes of existing technologies. I am now going to clarify why smart materials should be considered inseparable from 4D printing technology. Smart materials are considered materials that can respond in real time to an external stimulus, and they are capable of learning new properties (Schodek, 2005). Interviewed participants put emphasis mainly on the properties that belong to living organisms in terms of a kind of a natural revolution. Dr Lewko reflects this in the following words:

"*If your pipes at house gets blocked you have to open everything and replace them all so these active materials really have appeal, because many things will self repair. In the airplanes they meant to do very expensive maintenance just in case something goes wrong some cracks appear but If you have active materials, which do something when things go wrong, that's a really large appeal for many things.*"

8.7 Household/Environmental Issues

The technology of 3D/4D printing may find its place in households eventually, but to what extent is still unclear. As has been said, it is necessary to appropriately black-box the technologies before they become part of standard households. The ideal solution would be, alongside the development of the technology, to keep testing it with the interests of all stakeholders in mind, and through this to create an "informed prediction" (Verbeek, 2006) in order to form an effective black-box. It is already possible to procure a 3D printer for just 300 Euros, yet successfully operating one still requires some technical capability. In the media, 3D printing is often discussed in the context of domestic printing, especially in the worrisome case of homemade guns. However, the expansion of this technology can only come after the "killer application[34]" is found. After the discovery of the "killer application", it is very likely that the technology will become cheaper and thus expand into private homes, yet this does not mean that the technology will ever become part of a normal household.

The actors I studied foresee the trend known as "hobby-printing" persisting. 3D printing will likely be used at home only by people who have the time and resources to work with this technology passionately and devotedly, but even in this case, after some time these people will run out of ideas of what to print and 3D/4D printers will be put in the garage to be used only occasionally. Thus the most substantial part of 3D printing will consist of the prints that are going to be produced commercially. This is a very important aspect of the future development of this technology because commercial purposes create very favorable conditions for the application of this technology. These kinds of conditions will be never be raised in a normal household. Major obstacles are formed by high user demands, the technical skills required of the operators, and the requirements of storing the material needed for printing.

Whether or not this technology will ever become a standard household item, it has great creative potential. This creative potential, on one hand, can bring great benefits to society. These benefits, however, go hand in hand with the possibility of excessive use. This can result in an enormous amount of waste. From an environmental point of view, commercial production as

[34] See Chapter 10.1.8, Killer Application

well as private consumption must be constantly evaluated and re-evaluated. It is important to regulate the production of unnecessary things and to teach people how to handle worn or unwanted prints.

Insights into how 3D printing can turn against its user and the environment are offered in Sterling's (2011) novel "Kiosk". The participants studied in this project mainly focused on parallels to 2D printing, and the outlook for the technology along these lines of thought is very similar. Participants presuppose a reduction in production costs, which will first create a boom, followed by unwanted waste and overprinting. After a boycott of the undesirable consequences, an "ecological revolution" will hopefully follow. This parallel is very fruitful for increasing awareness of the potential environmental risks associated with this technology, so that once the promises of the technology become reality, the risks may be avoided.

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10 Appendix

10.1 Concerns about Matters of Definition

10.1.1 3D Printing

The most basic fact is that 3D printing is completely unrelated to traditional printing on paper or any other flat surface. If we want to be more precise, 3D printing is the process of bringing about the materialization of any three-dimensional (3D) idea into a tangible three-dimensional (3D) object. This technology creates the object through the addition of the material. This is in contrast to the traditional methods of manufacturing: the disclosures of which are typically generated by the removal of surplus of material.

3D printing starts with the creation of digital 3D drawings. Then data is cleaned by a special kind of graphics software, and finally, this process ends with the materialization of detailed 3D data into a physical object using a special 3D printer. The complexity of the process depends on the quality of the 3D printer and the materials used. Nowadays, the range of materials is so huge that it is difficult to find a material that is not possible to be used in printing. Furthermore, it is possible to combine multiple materials.

10.1.2 4D Printing

''Imagine a world in which solid material objects can morph into new shapes or change properties at the command of an individual or in a pre-programmed response to changing external conditions like temperature, pressure, wind, or rain. That world in which things are not quite what they seem—is on the horizon.'' (Campbell, 2015 , 1)

This is a method of printing where printed objects can self-assemble or change shape into a new form. In this process, the composite materials used in traditional 3D printing are combined with incorporate polymer fibers, smart materials, or programmable matter which has shape memory. The results of this application can be seen in the experiment where an object from six squares, folded almost flat, forms itself into a cube after being placed in water forms itself to the cube. The phenomenon is far more simply put by scientist Martin Dunn (2013), who explains in the interview at University of Colorado the process as follows: *"... the initial configuration is created by 3D printing, and then the programmed action of the shape memory fibers creates time dependence of the configuration—the 4D aspect."* . technology promises interesting possibilities for a variety of applications.

The art of this work with polymer fibers, smart materials, and programmable matter lies mainly in successfully configuring the right architecture, position, and orientation of the process, and in taking into account other key factors in order to achieve all necessary actions for the printed product to be assembled into the desired shape. The US military hopes that their research will lead to 4D print material allowing a car to change its shape or for the military to be able to control the structure of the fabric so that the uniform of a soldier can be changed and controlled as desired.

10.1.3 Actor-Network Theory

Actor-Network Theory is the product of sociologists associated in various ways with the Centre de Sociologie de l'Innovation of the Ecole Nationale Superieure des Mines de Paris (Law, 1992). During the eighties and nineties, an approach that extends the existing concept of the networking concept in sociology was developed in France.

Today, this theory is associated with a number of authors of French origin.

The basis of the theory of networks and actors is the idea that social actors do not act independently, but are instead linked in networks of varying size. These networks are heterogeneous, and involved in them are both subjects and objects—or, in other words, both people and "things" . From a methodological point of view, ANT looks at humans and non-humans as equal partners, and rejects the modern subject-object division of the world.

10.1.4 Additive Manufacturing

Additive manufacturing can be understood as a different term for 3D printing, in cases where the focus is more concentrated on the process of production. Various types of additive manufacturing exist: Inkjet Printing Powder, Fused Deposition Modeling (FDM), Stereo Lithography (SLA). and Laser Sintering (SLS). For each of these technologies, an object is formed by adding layer upon layer, but in different ways.

10.1.5 Black- Box(ing)

According to Sismondo (2011, 120): "the term ‘’black box” as an input-output device, which is predictable, and once it is known how the technology is going to work, the "black box" is closed by scientists or whoever has the control, and the closure of the technology is simply taken for granted."

10.1.6 Co-Production

Co-production, at its core, is "the proposition that the ways in which we know and represent the world (both nature and society) are inseparable from the ways in which we choose to live in it" (Jasanoff , 2004 , 2).

With the idea of co-production, it is possible to design frameworks through an analysis of social science practices and to furthermore explain individual practices by elaboration on scientific background and social conditions. It is crucial to understand the concept of "co-production" in the context of science and society. Co-production in this sense encompasses the co-evolution, co-dependency, and co-production of science and society.

10.1.7 Hackers

In modern society, hackers compose a group of curious individuals who want to reach a comprehensive understanding of how the technologies work, whether the focus be on hardware or software. They seek to find the limits and weaknesses of technologies, and many times they also provide solutions for dealing with such weaknesses. The true meaning of the word "hacking" lies in the way in which problems are solved. Hackers are divided into several categories (black hat, grey hat, élite hackers, script kiddies, and so on.) Hackers, as we define them today, have been among us since the 50s and the 60s.

10.1.8 Killer Application

Generally understood as the application of a technology that enhances the use of the technology to new dimensions. In this case, it is better explained through examples. "VisiCalc" software is considered a killer application for computers because it helped to find uses for computers both in business and in households. Another example is e-mail, which is seen as a key element for enhancing and spreading the use of the internet. In the words of Ing. Vogele:

"... [T]hey didn't know what to print, but that doesn't says that phenomena will not occur in the future and people will not learn how to use it, because it's like with killer app for computers, because it was like what are the computers for. Until there was no table processor like nowadays is excel for instance. After such a thing was put to practice, then suddenly everyone wanted a computer, economists, scientists, meteorologists. Because that was the killer app."

10.1.9 Massachusetts Institute of Technology ("MIT")

The MIT is a private educational research university in Cambridge, Massachusetts. The MIT has five schools and 32 academic departments, with a strong emphasis on theoretical, applied, and interdisciplinary scientific and technological research. The MIT is considered to be one of the most prominent and progressive universities in the world.

10.1.10 "Mindset-shifting"

This is a term used by one of the experts which represents shifting between technical capabilities and socio-technical imaginaries and knowledges. In the words of Dr Lewko:

"... [S]o mindset shifting... Technology itself didn't really evolve that much... so most of the things which you can print out now, you could print out 15 years ago too in a very similar quality so change was in the mindset of the people..."

10.1.11 Nanotechnology

Currently, there exists no single universally accepted definition of nanotechnology. Nanotechnology is not a new scientific discipline but rather a new area focusing classic science disciplines such as physics, quantum mechanics, chemistry, biochemistry, electronics, and so on into the development of materials, devices, and operating systems with special characteristics, arising from the quantum nature of matter. At present, there are many definitions of nanotechnology which are more or less different. The term "nanotechnology" is usually used as a common term that encompasses the various fields of nano science and nanotechnology.

10.1.12 Programmable Matter "PM"

Programmable matter is a term created by Toffoli and Margolus (1991). Programmable matter begins with a ‘’programmable’’ or ‘’computerized atom’’, but it does not end there. Scientists are able to change the physical properties of matter through its ability to perform process information.

‘’(t)he science, engineering, and design of physical matter that has the ability to change form and/or function (shape, density, moduli, conductivity, color, etc.) in an intentional, programmable fashion. PM may come in at least two forms: (1) objects made of pre-connected elements that are 4D printed or otherwise assembled as one complete structure for self-transformation, and (2) unconnected voxels** that can come together or break apart autonomously to form larger programmable structures. PM encompasses, yet goes beyond, a range of technological capabilities—including 3D printing, micro- robotics, smart materials, nanotechnology, and micro-electromechanical systems (MEMS), to name a few.’’*

http://www.atlanticcouncil.org/blogs/new-atlanticist/the-next-wave-4d-printing-aims-to-program-the-material-world (accesed October 3 , 2016)

10.1.13 Smart Materials "SM"

There exist many definitions of SM: I chose one from the McGraw-Hill Dictionary of Scientific & Technical Terms (2003): *"Materials that can significantly change their mechanical properties (such as shape, stiffness, and viscosity), or their thermal, optical, or electromagnetic properties, in a predictable or controllable manner in response to their environment. Materials that perform sensing and actuating functions, including piezoelectrics, electrostrictors, magnetostrictors, and shape-memory alloys."*

*(accesed October 3 , 2016)*http://encyclopedia2.thefreedictionary.com/smart+materials

10.1.14 Science Technology and Society "STS"

STS is an interdisciplinary field where the main aim is to investigate the links and interactions between science, technology, and society. "STS scholarship allows us to analyze the complex interplay of scientific and technological developments with other dimensions of social life." (Harvard Kennedy School. (n.d.). Frequently Asked Questions about Sociotechnical Imaginaries. (Accessed on November 6th, 2014 at http://sts.hks.harvard.edu/research/platforms/imaginaries/imaginaries-faqs/)

10.1.15 Sociotechnical Imaginaries

"Sociotechnical imaginaries are at once descriptive of attainable futures and prescriptive of the kinds of futures that ought to be attained. As an influential part of the currency of contemporary politics, these imaginaries have the power to shape technological design, channel public expenditures, and justify the inclusion or exclusion of citizens with respect to the presumed benefits of technological progress. Given the political salience of such imaginaries, and the risks and instabilities that inevitably accompany their realization, understanding how they are formed and implemented is necessary to any serious exploration of what the sociologist Ulrich Beck has called a "cosmopolitan" vision of inter-cultural collaboration and coexistence." (National Science Fund, 2007) (Accesed,October3,2016) http://sts.hks.harvard.edu/research/platforms/imaginaries/iii.proj/nsf-summary-and-proposal/

10.1.16 TU (Technical University of Vienna)

Founded over 200 years ago, the TU is now a place of education for about 18,000 students and cooperates with 48 universities worldwide. The Institute of Additive Manufacturing at the TU is also one of the most prominent in this field in the world.

10.2 Theoretical Sensitivity

Firstly I am going to explain what the term theoretical sensitivity actually means. The definition comes mainly from Strauss and Corbin (1990), and once I have established it successfully, I am going to explain how I increased my theoretical sensitivity by using Atlas.ti. Theoretical sensitivity is an important part of establishing a theory according to the GTM in order to ascertain the theory is really grounded, conceptually dense, and well integrated. Theoretical sensitivity refers to the personal properties of a researcher, which allow him or her to distinguish specific details about data. The researcher's mission is to extract as much as possible from empirical data. He or she must be able to observe the data and constantly ask questions. A famous biologist once wrote: "*It is not to see something first, but to establish solid* *connections between the previously known and the hitherto unknown that constitutes the essence of specific discovery*" (Selye, 1956 , 6).

In practice, this means that in the process of conducting research by using the GTM we must create and put together new categories rather than use a preexisting standardized way. If we become too attached to an existing theory, it could keep us away from reaching a discovery. The essence of discovering lies in defining new relationships between categories instead of verifying an already defined relationship. I am going to describe the work with the categories in the next subsection.

Glaser (1978) devoted a whole book to the topic of working with theoretical sensitivity and its sources, as well as techniques of increasing this kind of sensitivity. As has already been mentioned, theoretical sensitivity makes up the core base conditions for creating a theory which corresponds to the analyzed reality. Two main sources of sensitivity exist. The first is getting familiar with the studied literature as well as professional and personal experiences with the topic studied. This affects the research process significantly. The ways of using literary sources are explored more in the next paragraph where the possibilities offered by Atlas.ti are explained. The second source of theoretical sensitivity is the research itself, where not only does the previous collection of data affect the next collection, but further analysis of data is also influenced by previous research activities. It is necessary to maintain the difference between reality and what is created by the researcher. For this purpose, there exists a set of techniques. One is constantly asking questions and holding a skeptical attitude towards all categories and hypotheses brought into the research process or created during its infancy, and continuously monitoring them. Practicing the GTM developed by Strauss and Corbin (1990) should ensure the establishment of a grounded theory corresponding to reality and created with theoretical sensitivity. The manner in which I maintained theoretical sensitivity in my research is going to be described at the end of this section.

I have elaborated on all the aspects of theoretical sensitivity that I consider important, and now I will get to the point that I am going to argue: how I have ensured high theoretical sensitivity in my case, despite my lack of research experience. I had worked with the software Atlas.ti before this project. I used it almost throughout my entire master's studies. This fact gave me one big advantage. While working with all the academic texts from my master's studies, I had coded all the key concepts of the individual authors. This allowed me to compare the use of similar concepts by different authors, as well as identifying phenomena addressed and discussed by different terminologies. Thanks to this, I elaborated the whole of the STS field into hypertext, which allowed me to very effectively move through the field.

While I was very interested in and maybe even obsessed with the topic of my thesis, there was one disadvantage about the topic that I struggled with through my work. Despite the fact that 3D and 4D printers have a series of technical texts devoted to them, there is a lack of social science texts dealing with the subject matter. This made my work challenging—but thanks to this, also original. My state of the art research is based on general concepts rather than on the literature dealing directly with this issue.

Before I began my research, I studied a reasonable amount of literature; magazines as well as forums dealing with this topic. That was an important condition for me to orient myself with the issue, and to enhance my ability to be an equal partner in discussions with scientists during the expert interviews and in the focus groups. Without my diving into this subject, I believe the experts would not have interacted with me directly, and they would have resorted to explaining things too simplistically This often results in a deviation in measurements, and makes impossible to ask the more complex questions that occurred in the interviews. For example, reading about cases in the US where people are printing guns at home and familiarizing myself with the general statements of the inventors of 4D printing technology at the MIT broadened my vision about the issue, and at the same time raised a lot of questions[35] that I could ask the experts in order to get exhaustive answers and more information. The theoretical literature increased my sensitivity and allowed me access to the core information during the expert interviews. The most serious features of individual testimonies became clearer still after repeatedly listening to the data during the transcription process, and by the subsequent coding of the interviews.

The public statements from researchers at the MIT increased my theoretical sensitivity, and after the initial interviews I was able to formulate and ask questions with more depth. A great benefit for me was the opportunity to contact the experts again and to ask them additional questions, which helped me to complete the missing data. However, this was only necessary in two cases. Interviewing experts was a very beneficial way of asking pertinent questions and increasing my theoretical sensitivity before conducting the focus groups with the hackers. In each of the focus groups, I tried to maintain an open venue for the participants to express their own opinions, which were prompted by previous findings and statements visualized on cards (IMAGINE[36]) (see Felt, Schumann, Schwarz, and Strassnig, 2011). Further along, I asked questions that led hackers to take stances on the views of the experts. This allowed me to explore the differences of opinion in greater depth. The differences in opinion were, however, minimal. The main cause of different views on the issues could be traced back simply to the different environments of the individual actors (institutionalized vs. un-institutionalized).

[35] See Chapter 4, Research Question

[36] See Chapter **Chyba! Nenalezen zdroj odkazů.**, "IMAGINE" **Chyba! Nenalezen zdroj odkazů.**

Descriptions of these differences are going to be elaborated on in the following sections where I am going to discuss them in depth.

The hacker focus groups also had a big impact on my theoretical sensitivity, developing constantly during the discussion which lasted approximately 60 minutes. It was interesting to observe how the statements of individual participants mutually influenced each other, and how the different statements also increased the theoretical sensitivity of participants. In particular, I noticed that inquiring after the participants' personal views on the scientists' attitudes had a big impact on the interactions between the participants of the focus groups. Aware that such distortions might occur, I tried to keep the focus groups running in the way I explained above. I began with the introduction of the cards, where I randomly pulled a single card with a statement made by a scientist about 4D printing. This always kicked off a discussion and let the hackers express their personal views on the issue. I tried to lead a focus group in a way that participants who were dominant and whose statements significantly influenced others were heard mainly at the end of each subtopic.

The manner in which I have encoded and thus identified the individual categories will be made clear in the next section, while exploring increased theoretical sensitivity is going to be explained only marginally. I hope that the importance of the process of increasing theoretical sensitivity will be obvious to the reader. As mentioned above, theoretical sensitivity refines the research throughout whole process, and it was necessary for harvesting all the data to assure that I reached a "theoretical sampling", which I am going to return to later in the following sections. I will return to all the data and use the program options to hide previous coding and code all the data again, just to make sure that I did not miss anything important.

10.3 Conceptualization by Coding

This chapter briefly outlines what categorizing is, and focuses on its importance for the development of applying the GTM. I also explore the design of the codes (as sketched out in Chapter 3.1.4, Scientific Software) dedicated to working with Atlas.ti and its contemporary development of employing the GTM. Coding, in our particular case, allows us to effectively manipulate the codes. This in turn allows them to be exhaustively developed into various matrices, which enhances theoretical sensitivity by describing the conditions and the causality of the phenomena researched (Strauss and Corbin, 1990). A description of the analytical process is essential for understanding the theory. In this chapter, I am going to finish the theoretical explanation of my understanding of the relevant theories for empirical qualitative research, and in the following sections of this thesis, the data will be interpreted, analyzed, and evaluated.

"Category" is a very important analytical unit, which enables us to describe the world around us. While we use "categories" in everyday life for finding our way in and around society, but according to GTM research, it is also necessary to precisely define the relationship between different categories, and to constantly compare subcategories with categories. Regarding the GTM and this particular comparison, we can observe an overlapping of inductive and deductive techniques of data processing. In this way, the GTM and this technique of elaboration combine the theory and its verification. Glaser and Strauss (1967) point out that the emergence of ideas contributes to the creation of new theoretical ideas. I conceived this theory of creation as work with categories while working with Atlas.ti, because the software allowed me to use categories and to make them behave like actors in a seamless web: actors who try to mirror reality and to reflect facts. Working with categories includes acknowledging not only the complex, intertwined, and specifically defined relations between them, but also their individual definitions. Although categories do not exist in a metaphysical sense, they create a tool through which we can observe a given social reality. Various features and "facts" of social reality are densely intertwined and thus closely interrelated, and they influence one another. By creating a semantic network in a virtual environment to connect and link concepts, we are capable of emulating the relationships and features of the objects under scrutiny, which brings us closer to reality and leads us to a new and fresh look at the investigated reality. Such a virtual environment is created on the basis of categories that are grounded in the data. However, it is important to remember that the computer only helps us memorize our own thought processes and remains unable to think by itself. Thoughts about the GTM are produced by and based on the categories grounded in the empirical data through a systematic comparison of data and a continuous testing of ideas. The process of analysis by deduction and induction that usefully combines both is called "abduction" (Blaikie, 1993).

It is important to understand the relationship between concepts and categories because although they can sometimes be understood as synonymous, in this case they focus on different aspects of meaning or mental content. Each category is also a concept because it is defined by some properties, and each concept is also a category as it enables us to sort studied phenomena. Both of them are characterized by a code, but nonetheless it is necessary to differentiate between categories and concepts. It is essential to distinctly and strictly define the relationship between the two. Though such procedures, we can examine the features of each to determine their quality and relevance to others. Through the practices described above, it is possible to focus on the causal relationships that are important to understand, as they allow us to elaborate on and to describe reality under specific methodological considerations.

Strauss and Corbin (1990) consider concepts the elemental building blocks of theory, which enable the researcher to use the analytical method of questioning to identify particular details and differences. This allows for the merging of similar cases in the category. Also, Strauss and Corbin (1990) describe three possible types of the formation of concepts or encoding: open, axial, and selective. Differentiation is essential for good orienting regarding codes and efficiently working with them. The most extensive and concrete level of coding is considered to be open coding, where relevant categories are segmented and identified into a main category on the basis of their specification, dimensions, and characteristics. I need to reflect shortly on this process and point out that, in my research, I used open coding countless times before I reached the point of inclusion of all relevant statements under relevant categories. I needed to go back and forth many times because this practice allowed me to find out what data were beneficial for investigation. During this level of encoding, I began to notice that despite the fact that individual participants described matters in different ways, I was able, based on certain similarities, to begin to combine similar segments under general categories. This is also called axial coding. With the above-mentioned procedure, it is also associated with the process of narrowing down questions and thus increasing understanding of the phenomenon. I am going to bring up an example.

In the context of my research, the phenomenon mentioned above means that I asked questions about 4D printers with reference to MIT researchers. However, gradually, I figured out that this terminology (4D) is not really respected in the community of people engaged with this technology. I then began to inquire whether they know why it is called 4D printing. Depending on the situation, I explained in various depths to the interviewed experts the definition according to the MIT, and after the introduction of definitions, I asked them to express their opinion on the terminology. The point is that this new technology has not yet been black-boxed, and therefore has no stable name. Paradoxically, each of the experts chosen for interviews already worked on this technology to a certain extent. This increased my theoretical sensitivity and encouraged me to focus on the additive manufacturing of smart materials during the process of data collection. In one sense, the technology under investigation here actually can be classified a 4D printer. As described by one of the experts, a similar process of terminological debate took place when 3D printing officially received its name:

Ing. Vogele: "*From this aspect it's more of a branding trick, but still for me it doesn't matter in the sense of interiority of discipline in the sense that its evolution anyway, whatever will called it, maybe one day will call it better way and we'll have more instances of this kind of printing than maybe people will figure out, ok, let's call it different way, Same like with 3D printing, because before you know. Each company thirty years ago, each company which started the process of additive manufacturing in their own way, they all used to have a different name for that. So every company called it by different specific name, it wasn't 3d printing it was: fuse deposition modeling, it was stereo typography. It was laminate object manufacturing it was you know… you can find like seven names. But then maybe like seven-eight years ago, where was enough kind power of the industry and they realize that now it's going global in the sense that it reaches masses and also* *going in to industrial production because it started to become more fast and more precise and more cheap and more high quality materials and quality control, which is very relevant.*"

In a similar way, while I was summarizing the categories more and more in order to capture the diversity of opinions, I came to the point where I had determined a number of relationships and categories which were described by their properties. The initial benefit of interviewing scientists was that much of the interviews and later interpretations thereof could be used as "vivo codes" (Glaser 1978, Strauss 1987). Furthermore, some of these had not been adapted to the third phase of the coding process (selective coding) and allowed better encoding in the hacker focus group, owing to the accuracy of definition regarding the categories used by the scientists. In both cases—expert interviews and focus groups—I had come to a point where I stopped including new data and findings. Thus I reached theoretical saturation, and the research was completed.

I had now shifted to the second stage of my empirical journey, and focused only on analyzing the data. In the process of coding, I distinguished two levels of encryption, which gave me a good overview of the categories and allowed me to be sure that I did not miss anything.

During the encoding process I had created network diagrams on which I had been drawing relationships between categories, which helped me also to concentrate on the data. As soon as something occurred in my mind regarding a given statement, I wrote down a note about the idea. When creating categories, I tried to define them through existing statements of opinion—in other cases, I commented on them with my own words. While related categories were gradually created by open coding, I began to employ memo notes, through which I discovered a link instrumental tothe creation of axial coding. Strauss and Corbin (1990) note simultaneous overlaps between these two levels of coding. One cannot be without the other; the two distinguish different levels of theory.

In the paragraph above, I described the procedures of applying a specific theory that described various actors and, at the same time, the reasons for their attitudes, points of view, and positions towards additive manufacturing of SM and PM. Using this particular theory of empirical analyses, I am now going to discuss hackers and experts separately.

First, I am going to elaborate on the differences between experts and hackers, but as I dive more into analysis, both experts and hackers will be shown to ultimately complement each other in an interesting way. The second theory, which Strauss and Corbin (1990) explain as "generic" works to generalize all actors. In our case, the transition between the first and the second theory opens up the comparison between hackers and experts.

I use these phases of work so reader will be able to get a more thorough understanding of the characteristics of the attitudes of the scientists and hackers involved with this technology.

By continuous comparison and generalization I reached a "theoretical sampling" as Strauss and Corbin (1990) call it, by which I ensured that there is a very weak chance of gaining new data or establishing new categories.

I went through my notes dozens and dozens of times in the hopes of getting to a core category. I encountered more than enough dilemmas. Several categories were repeated until I came up with the idea of merging them. I will mention some of the following categories: black-boxing, regulation, gun printing, army use, market aims, and so on. During the analysis, I wanted to give up. The number of tools in the program has helped me to understand the data in more depth. However, coming back to what I said earlier, computers only help the storing of data, but they cannot think by themselves or come up with a core category. In the evenings when I was falling asleep, I was thinking of only one thing: the controversy that influences the development of technology through the behavior of the actors included in decision processes. When I woke up the next morning and started to re-analyze the data and sort categories which had previously seemed little but blind alleys offering only one interpretation of the data, I came to realize that in almost all the empirical data, controversy was a category, and that was when I knew I had unraveled what the core concept was. Eureka!

If I have understood Strauss and Corbin (1990) correctly, this process is called "selective coding".

By using this central category and defining the core concept, I managed not only to discover relationships that I had not been able to see before, but a most appropriate category was revealed for the further interpretation of data. I started browsing the data and combining categories in new ways. First, I was afraid that I might be missing some data, but I soon realized I had everything I needed. Next, I will conclude this section of data analysis methodologies, and move on to the interpretation of data.

10.4 Hackers (Group A)

The first group of hackers consisted of people that I could refer back to for sharing a philosophy of engineering technology (Mitcham, 1994). Thus the participants were mostly students and manufacturing employees. or affiliated with companies who are either researching this technology on a theoretical level or using this technology in practice. These individuals make up the precise group of actors who are working with this technology in the field of either the academic or the commercial sectors (Triple Helix). Students tend to focus on interesting internships, and this is why students from technical disciplines are attracted to internships in progressive companies. These companies today tend to use 3D printing because of the relatively modest possibilities of prototyping. People employed full-time in such companies must have expertise in the field in order to be employed. I have already expounded on the co-production of technology and the sectors of academia and business, and this connection is perfectly illustrated by the first group.

This group strove to idealize the technology, and saw in it a path to a modern society that can handle the juggernaut of risk (Beck 1986). They predicted a society that is able to properly handle the potential adverse effects of putting the technology into practice. I do not condemn their attitude, but this group might to many sound somewhat utopian. Furthermore, while the group offered few sci-fi scenarios, they retained a special form of objectivity. The main starting point was what opportunities this technology has in store. They said scientists have downplayed the potential risk, but this was not a bad thing because it offered a glance as to what direction the technology could evolve, and how the best direction could be developed and nurtured. In this group, the participants focused on the endless possibilities that smart 3D printing materials could bring. One of the participants at the end of a focus group, after having been informed of the statements of the scientists, said:

"*Smart material reacts with environment in a very new way, what definitely change all known. The old world is not going to exits any more as we know it. The fact of the combination of articles create a very different substance, that is something other. It's something as a God article. So controversies of 4D printing is based in printing technologies and not a particles. that all bring endless ways of use, script and descript. So that is disturbing. You can be pragmatic MIT way. You can be skeptical like a Austrian way. If you want to be skeptical You can look at technology of 4D printing with use of frame of Gardner institute hyperbole and say there was a lot of technologies and we don't need any new one. So that could be linked to PC and its killer application so when neither director don't believe in exploration of PCss. An after coming of killer application everything changed.*"

This group shares the position of the scientists when it comes to the name 4D. When asked about their opinion regarding the MIT's statement which accompanied promotional videos released, one of them said:

"*This 4D is without dimension of time and action. People see just two dimension, and name 4D is nonsense, and the discourse is controversial.*"

They considered this terminology in a similar manner to Dr Benedetti's view: it exists mostly for marketing purposes and self-promotion. No one agreed on what possibilities this technology could bring. The promotional videos from the MIT had the hackers impressed and affected their view on this issue. Perhaps the legal expression of these scientists prompted the participants to agree with the statement which was mentioned in the previous paragraph. In this sense, framing this technology in this way probably served its purpose. According to this group, a similar representation of this technology could increase public awareness as well as encourage young people to become devoted to this technology. People tend to fear things that they do not understand. This is why, according to this group, a carefully thought-out popular presentation of this technology could shape the view of the public in the direction of accepting the technology as something that is now commonly used and not a scarecrow. Participants noted that although this name is not correct and there is not really such a thing as "programmable matter", no matter how it is called, it is more important to focus on how the technology hidden underneath a suitable marketing name is presented to society.

Regarding the use of this technology in today's practices, participants focused on the new possibilities that this technology offers. Not only can it create sophisticated components, but it can also be used to produce new material objects in a very short time. An important feature is its ability to create very complex components made of steel or stainless steel, such as aircraft turbines and engines for cars. This has the research potential of a team being able to create a new turbine made of material that corresponds to the strength of the constructed component part in the traditional way, and once printed, tests can be run straight away. With the help of the technology, satellites can also be launched into orbit to print spaceships. In this context, the participants criticized the problem of the accuracy still affecting the technology, which is why additional work by C & C machines[37] needs to be done on the machines to eliminate the possibility of small errors. Nevertheless, the group believed that the problems will be eliminated, and that the will become a dominant one once the technical issues have been resolved. They agreed that the emergence of 3D/4D printing technology can be seen as the third industrial revolution (Rifkin , 2011). The group also hopes that many societal benefits and changes will occur. They also proposed the idea that mass production will be replaced with tailored components. Thus, every plane and every car in the future would be a unique piece of work, from the chassis to the spark plugs in the engine. These participants believed that this technology will lead to the transformation of society and stimulate the creativity of the human spirit and the use of human potential.

There were opinions about where this technology would be used. It was suggested it would not only be used in the engineering industry, but also in the areas of culture such as art. The possibilities of new shapes, mentioned by Ing. Vogele, presented a really interesting chance for participants in this group to think about art in connection with additive manufacturing. Art enthusiasts saw in this technology ways of creating new sculptures and new instruments. Regarding the graphic use of this technology, the participants considered that surreal paintings and sculptures could be created alongside putting the technology to use in the film industry.

[37] Computer Numeric Control (CNC)

"*Ability to print smart material allows you to create animated characters in real size that can mimic human facial expressions, it can allow the film to make the conclusions of fantastic characters that look really real. Thus, it would not need months or even years of study spent at a computer cartoon characters with different actions, but it would be enough just to make a single 3D model, which should be printed and able to play its part in all of the footage without sketching the characters in the image. Thus, Garfield, famous talking cat would be resented in the hands of its owner, but I really would lay them. This gave an unprecedented engagement by the authenticity of a real illusion.*"

This group saw 3D/4D printing as a technology that will change everything and there will not remain an area that would be unchanged. Too much was discussed to cover all of it in this work. Other possible applications are in biomedicine with the development of medical procedures that will lead to the prolongation of human life, if not to immortality, as well as the emergence of new foods or 3D printed meat, which could eliminate the need to keep animals in cages. The food replicator from Star Trek was also mentioned, and not just in relation to food production in space, but also for the production of entirely new foods, which could in turn bring about a lot of undesirable consequences. This group, through its idealized attitude to this technology, did not see this as a problem but instead as a way to make mankind appreciate natural things more.

"*Every day forests around the planet are disappearing, which is of course terrible, but thanks to this people managed not only revealed a number of endemic species, but many of them saved from extinction. Like it is with the natives. On the one hand we destroy their habitat and cultures that have survived unchanged for thousands of years. This supports fascination for western people for untouched pieces of nature. For us, people living in the wild are not only savages, but happy people living in paradise on earth.*"

Dr Sonquist also spoke of human craft being of utmost importance. Human work is always going to be appreciated, and the members of this group shared the view. They especially noticed the dichotomy that the more we transform the world around us and the more we are able to produce automatized products, the more we appreciate handmade products. Thus, handmade work begins to stand out in even starker contrast to automated production.

The participants in this group could not agree on whether the technology is going to become a part of households or not, but they underlined that the third industrial revolution (Rifkin, 2011) should be something that allows people to think in new ways about the world around them. Thus people will start to conserve materials. This group views 3D/4Dprinting technology as something that will make people be better and have more control over their creations. In this sense, the group also predicted the emergence of the "fifth dimension" in additive manufacturing, which enables the print-out to be folded back after use. During the part of the debate when we discussed the environmental side of things, I recalled Dr Benedetti's example of the sofa. The group, when discussing the environmental consequences, reached a vision for the future development trend of 3D/4D printing as a "print" not only being able to fold back, but also capable of becoming completely decomposed.

"*I see this technology as the future of ecological approach. Like today supermarkets are selling plastic shopping bags, which can decompose into dust, I believe that the future printers will be able to print almost anything so that prints will be able to completely decompose to dust and by that not burden the environment.*"

This statement is again a proof of the tendency of the participants ofthis group viewing this technology as a way to make the world a better place. It is also based on the belief that humanity can learn lessons from their mistakes.

Regarding the regulation issues of this technology, this group's thoughts coincide more or less with the positions of the scientists, arguing that any degree of regulation could slow down—if not completely stop—the development of technologies, and that determining effective regulation in this stage of the development process is impossible. When I asked whether they had heard about the 3D printing of weapons, they said that they had heard about it on the news, but they are not worried about the misuse of this technology because not everyone can operate it effectively. The only meaningful form of regulation that this group can consider in this stage is in making manufacturers commit to the use of environmentally friendly production methods. Thus, in the case of 5D printers, manufacturers should be compelled by law to use technologies proven to avoid environmental contamination and damage.

This group did not want to pay too much attention to regulation because they did not consider it necessary in this stage of development. The main contribution by Group A to my research was that they offered a glimpse of how this technology could affect society in a positive way.

10.5 Hackers (Group B)

The second group consisted of participants who shared the view described in "Humanities Philosophy of Technology" (Carl Mitcham, 1994). The group was mainly composed of artists and freelance domestic inventors. These people had one thing in common: they did everything on their own, which on one side results in many obstacles and hard work, but on the other side, also yields a sense of freedom to their lives. As has been mentioned several times, the science and development of various technologies has often been done in collaboration between experts and lay people (Meyer, 2013). Access to "free thinkers" has been very important in establishing how the eventual black-boxing might look like. This is in line with Verbeek's (2005) idea that technology, together with its development, should be tested by all stakeholders and as well as lay people. It is necessary to put into practice the principle of construction technology assessment, and to see how the options work with in-scripts and black boxes by making use of the involvement of all actors in order to create an appropriate framework for this new technology. This focus group allowed me to monitor the relationship of scientists and lay people from another point of view, through which I gained better insight into the co-production of this technology. The group was very distrustful of institutionalized and commercialized science, and generally everything that represents the modern state. Despite the concerns of participants, they were keenly interested and diverse enough to act as a counterpoint to the first group. The main feature of this group was not the fact that the participants deal with 3D/4D printing at home, but the fact that they work and develop it independently without any supervision from an institution. This group also rejected the outcome of statistics mentioned by Ing. Vogele. This outcome he predicted that people, after a few months of printing, would no longer know what to print, and the printer would become an unused dusty thing. The following statement expresses this view well:

"*At work we use 3D printing mainly for promotional materials, and we really liked the possibilities it offers. Along with some colleagues we purchased three 3D printers at home, because at work we cannot "play with 3D printing". I have two small children and they always break something, but I don't remember when was the last time I had to buy something because they broke it down. I just printed it. With this all the ideas to print have started. With colleagues we routinely use printer to in new ways and on weekends instead of going to cottage, we sit in front of computer, draw and print. I was most proud when we managed to reconstruct an exact copy of BMW 328 in mini form, I wish I could print a real one, hopefully one day.*"

Of course it is possible that the participants were only bright and positive exceptions to a rule, but I leave it to the reader to judge. A special case were freelance artists for whom 3D/4D printing is the gateway to the creation of shapes that would otherwise be impossible to construct. Their biggest inspiration was nature, from which they capture natural motifs by using 3D scanners. These are put into a computer, edited, and combined in various way to produce a completely new design. However, the formations of these artists, as they say, are not always met with understanding on the part of the public or other "non-artists". The participants have often encountered incomprehension of their surroundings in fulfilling their vision, which may encourage their incredulity towards society. Everyone from Group B was very interested in public and global affairs. These two aspects of the group could also underlie their distrust of powers. This distrust was reflected in their viewing every institutionalized use of this technology in terms of political goals. Group B was very skeptical about the the idea of the whole society reaping the benefits of this technology. With them aware of the wide possibilities of this technology, they fear that the technology will be more destructive than constructive. In response to my question about where they see the future applications of this technology heading, one of the participants began to talk about how 3D/4D-printing applications could helpful in developing countries because the applications could increase their autonomy. This participant was stopped by another participant with the following statement:

"*Why is 4D printing not going to be used in Africa? What do you really think?! There is no fucking water. Thus realize, it is more probably the technology will be used in more economic ways. A few of people will be able to handle technology.*"

"*What other answer: Unfortunately, Africa will be the last place where would go 4D printer. In production is revolutionary because of smaller losses, but it is unbounded and omnipotent.* "

These statements are very demonstrative. They superbly portray the skeptical spirit of the group while enforcing my belief in the appropriateness of choosing focus groups as a method. This group saw the technology of 3D/4D printing as a future technology, but they saw it as the third industrial revolution (Rifkin, 2011) rather than devolution. According to them, this technology offers possibilities that are going to naturally be used for evil purposes.

"*Well 3D printing is a nice thing, it gives new opportunities, unfortunately man is a selfish being and selfishness never lead to social benefit. Jean Becquerel discovered radioactivity, which was firstly used for medical purposes, but paradoxically he died of the consequences of radioactivity. It took less than 60 years when was nuclear weapons first used on civilians, so it is only a matter of time before the creative potential of this technology is going to be misused for belligerent purposes.*"

This participant was not far from the truth because the US Army is the main investor in the technology of 4D printing. This is partially why their concerns are in place. In this group of participants, one member pointedout the scandal with 3D printing of guns in American households and unleashed a heated debate. The group discussed the options to print a single-use sniper rifle at home, or a detonator for a bomb, as well as the possibility of creating sophisticated arms for the weapons industry. The first concern of the group was the possibility that 3D/4D printing could be used for terrorist attacks. I am going to dive in and elaborate more on the military aspect of this technology in the context of regulation. After playing a promotional video by scientists from the MIT, this group expressed similar views as the previous group in regards to the name of technology. They also mentioned the creation of a marketing strategy simply by naming something with a fresh name. According to them, additive manufacturing changes the market in dramatic ways, and it may result in uncontrolled development, which in turn can enhance the adverse effects brought about by modern society. This leads to institutionalized distrust, mainly because institutions are seen as the right hand of political objectives. The participants particularly criticized the fact that although scientists design and develop technologies with the best intentions, they have almost no influence on how the technology will be put into practice. The group viewed this as part of the mechanism which maintains the social hierarchy.

"*Those who think that in five or ten years we will have all 3D printer at home is in my opinion a bit naive utopianism or communism that we will all have a everything same. D, but it's never like this with anything because in reality society is build on hierarchies and for people from corporate environments suits that the technology slowly dwindle and they may sell printers for half a million, but again that price is not completely inflated, since research and cost a lot of money. Development is the most expensive but I'm talking also about series production, which of poor quality and reduces the cost compared to the minimum selling price. However research would turn itself inefficient, so it is obvious that the developers hold the know-how.* "

In this sense, this group sees the abuse of technology for political purposes as a matter that we cannot change: as a thing which needs reconciliation. The way in which we can fight this is by trying not to be dependent on corporations that are nowadays many times much more powerful more than the state. This group saw the future of this technology in terms of reducing production costs, yet with ordinary citizens being prevented from benefiting of using the technology at home. This group sees regulation in an especially negative way.

In the regulatory field, the group sees this technology as something which cannot become "black-boxed". They see the problem mainly in the mindset-shifting, similar to what Dr Lewko brought up. They do not think that people are ready to use this technology. Rather, they take its misuse or excessive use for granted.

"*Additive manufacturing is very progressive technology and it is possible that through marketing arrangements nearer the user, but it will not reduce their independence, but believed it could increase the production of waste, because people will push stupidity, only for it because they can. And it earns the market anyway. No matter whether the technology to use green or not. If this technology will cause pollution, the market just to earn it again. For example, the fact that a lot of money, whether state or the user will dispose of unnecessary printouts.*"

The participants of this group described, in the context of environmental issues, that regulation in their view was very closely related to what Kiosk originally discussed (Sterling, 2007).

"*Despite the save of materials during production, reducing of production prices can result in consequences of excess waste. Excessive freedom predicts this technology to abusement. The question which remains is what positive impact the technology can have once the destructive component will subside?*"

This was a somewhat rhetorical question, as none of the participants responded to it. I am going to focus on this and try to find the answer later. Right after the last quote from the focus group was uttered, one of the participants followed up the on debate about the military use of this technology. The participants of this group have rather different views on the potential future development of this technology when compared to Group A. Instead of talking about the "God particle", they discussed so-called "super weapons" by imagining objects like the DT-1000/prototype series 1000 terminator from the movie *Terminator 2: Judgment Day* as indestructible homicidal robots. In this sense, they share the view of Ing. Vogele that there will always be people who are willing to abuse a technology for their perverse ideas.

"*3D printing has a great potential of use, which is also a potential to be abused, and there is no way to prevent it. This is not about whether a few people will print a gun at home, but about possibility for military to create a weapon that is unstoppable, which may result in extinction of humanity, or at least civilization as we know it today.*"

While the group predicted yet more apocalyptic visions, this was probably the most terrifying one. In summary, I could say that this group saw the technology of 3D/4D printing as a genie in a bottle. The technology could flood the world with waste and promote the destruction of humanity. The development of new, more efficient weapons may bring about weapons that will be less destructive- Nevertheless, paradoxically, according to the group the technology can also produce arms that will be more and more damaging than any previously existing weapons. In this sense, it is not going to matter that much how the technology is called.

"*Question about this technology is about if it will become constructive or destructive. So it does not matter what name will be chosen for the technology, but at the it matters if will be particular phenomenon constructive or destructive. If it makes will put society to sin, or if it will be helping for? It can easily turn to destructive.*

Another question is whether Can a 4D be a killer application for printing that is killing? It is something as medicine, it can be helpful or poisonous."

Very controversial views were also brought forward by some of the participants of the group in relation to the problem of coup values. The point is that additive manufacturing could eliminate all human activity. Handwork or manual jobs could be lost completely. The positions of craftsmen and producers as we know them in today's society could disappear. Another thing is the printing of human organs. I talked about this with participants with a focus on the situation in China, where researchers have allegedly reached the point where it is becoming possible to produce human organs in such a manner. The focus group reacted to this information by saying that if it were be possible to print a whole person, human life as we know it today could lose value. In this way, the natural reproduction of the human species could be pushed into the background, which is dangerous for the well-being of the mother and the child. Thus the wealthy could be kept young and be "reincarnated" into a new body, while the poor could be dying of diseases caused by environmental contamination and waste. The attitudes of the participants from Group B may sound like sci-fi, but they outline a much bigger problem. The fact is that this technology brings in its wake a lot of controversies that we cannot adequately respond to, and we cannot yet address the risks that this technology brings.

11 CV

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