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Sustainable Business Models for 3D Print

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ABSTRACT

The most important engineering puzzle that the policy makers around the world have to solve is how to produce economic well- being for most of the people, when monetary policy simply doesn't work.

3D printing systems are digitalized, democratized, and globalized manufacturing systems that handle tremendous complexity and collaboration. Therefore, they have created the necessity to be formulated or depicted in terms of a sustainable business model rather than a conventional business model that primary focuses on creating value in monetary terms.

In cooperation with HAGE3D, the master thesis conducted at the Institute of Engineering and Business Informatics (TU Graz) contributes in continuation to the previous research work by generating descriptive knowledge through a case study in the process of moving from a conventional business model to the creation of a new sustainable business model for a 3D printing system manufacture. The work had identified the drivers and challenges associated with the process of change, and the tools that helps in the creation of a new sustainable business model.

ZUSAMMENFASSUNG

Das wichtigste technische Rätsel, das politische Entscheidungsträger überall auf der Welt zu lösen haben, ist, wie wirtschaftlicher Wohlstand für den Großteil der Menschen produziert werden soll, wenn Geldpolitik – vereinfacht gesagt – nicht funktioniert.

3D-Drucksysteme welche digitalisierte, demokratisierte und globalisierte Fertigungsverfahren sind und welche enorme Komplexität und Zusammenarbeit bewältigen, haben die Notwendigkeit geschaffen im Sinne eines nachhaltigen anstatt eines konventionellen Geschäftmodells, das hauptsächlich auf monetäre Wertschöpfung fokussiert, formuliert bzw. dargestellt zu werden.

In Zusammenarbeit mit HAGE3D trägt die Masterarbeitsforschung am Institut für Maschinenbau- und Betriebsinformatik (TU Graz) in Fortführung der bisherigen Forschungsarbeit dazu bei, beschreibendes Wissen durch eine Fallstudie im Prozess des Übergangs von einem konventionellen Geschäftsmodell zur Schaffung eines neuen nachhaltigen Geschäftsmodells für Hersteller von 3DP-Systemen zu generieren. Die Arbeit hat die Treiber und Herausforderungen, die mit dem Veränderungsprozess verbunden sind sowie die Werkzeuge, die bei der Schaffung eines nachhaltigen Geschäftsmodells helfen, identifiziert.

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Dedicated to the Unknows…

- The Unknows, with whom one spends a boarding school life of 13 years.
- The Unknows, who teach the importance of humanity, inclusion, and diversity.
- The Unknows, with whom one travels, and explores his/her own definition of life.
- The Unknows, who exercise the phenomena of fellowship.
- The Unknows, who help students in their research with a dignified professionalism.

These Unknowns (to majority of world citizens) are the only knowns of my life, i.e. my fellow friends, my schoolteachers, and my research-supervisors. And my family (to whom life existence is about meaning, that desires to pursue knowledge) will also agree on their (Unknowns') importance in my life. These Unknowns will always be the intuitive norm entities of my search.

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ABBREVIATION

3DP	3D Printing
AM	Additive Manufacturing
BM	Business Model
BMC	Business Model Canvas
BMD	Bound Metal Deposition
CAD	Computer- Aided Design
DED	Direct Energy Deposition
EBAM	Electron Beam Additive Manufacturing
FDM	Fused Deposition Modelling
HFFS	High Friction Feeding System
LENS	Laser Engineered Net Shaping
LOM	Laminated Object Manufacturing
MJF	Multi Jet Fusion
MDG	Millennium Development Goals
NGO	Non-government Organizations
PBF	Power Bed Fusion
SBM	Sustainable Business Model
SBMI	Sustainable Business Model Innovation
SD	Sustainable Development
SDG	Sustainable Development Goals

SLA	Stereolithography
SLA	Selective Laser Sintering
SLM	Selective Laser Melting
SLS	Selective Laser Sintering
SMBA	Sustainable Business Model Archetypes
SME	Small and Medium Sized Enterprises
SOI	Sustainability-Oriented Innovation
TLBMC	Triple Layered Business Model Canvas
UAM	Ultrasonic Additive Manufacturing
UN	United Nations
UV	Ultraviolet
VBN	Value-Based Network
VMT	Value Mapping Tool

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RESEARCH INTENT (PART 1)

1. Introduction

"Global temperature rise…warming oceans…shrinking ice sheets…glacial retreat…decreased snow cover…sea level rise…extreme events…ocean acidification" (NASA, 2019) are compelling evidences for rapid climate change. The voice of reason and compassion (across all the global stakeholders) demands for the new ways of doing sustainable businesses as the world faces unprecedented environmental, social, and economic challenges (Business roundtable, 2019; WEF, 2020). Integration of sustainability and business is a process, attained by creating social and environmental values, as well as economic values (Elkington, 1998). To address the key issues, such as a climate change, a transformation from a solely profit-oriented business model (BM) towards a sustainable business model (SBM), which targets human, social, and environmental aspects will be inevitable by companies (Geissdoerfer et al., 2018).

On the other hand, the technology, that has the potential to play an important part in the transition towards more sustainable industrial systems, in terms of manufacturing is called the 3D printing (3DP), which is also known as additive manufacturing (AM). The 3DP in a long run will change the conventional way companies run their businesses, and this technology can't be viewed simply from the lens of conventional manufacturing technologies. This shift from conventional manufacturing technologies towards 3DP has enabled many companies to revise their BM. Since, the transformation of BM for 3DP is on an exploratory stage therefore, the significance of such technology towards topic like sustainability remains unclear. (Ford and Despeisse, 2016; Öberg et al., 2018)

This thesis adopts a BM perspective to generate an understanding on the process of creating a new SBM, and represents the practical applications of existing tools and frameworks, including a stakeholder map (Fassin, 2009), a value mapping tool (VMT; Bocken et al., 2013), and a business model canvas (BMC; Osterwalder & Pigneur, 2010). It reviews the current knowledge on sustainability, SBM, and 3DP during a desk research. The thesis further represents the results, of an explorative study conducted in a holistic manner to create a SBM. The research method applies a single case study design, based on a desk research, and the qualitative data obtained through an interview and a workshop, on an executive management level (Yin, 2009).

The work of research was conducted at the Institute of Engineering and Business Informatics at the Graz University of Technology in a close cooperation with the company, HAGE3D GmbH (HAGE3D, 2019), a 3DP system manufacturer. The partner company wants to target the medical market, with their products using the material extrusion technology (ISO/ASTM, 2015). This decision on the management level has created an opportunity to create a new BM for the medical market, which in a long run should be sustainable and flexible for the company (Ford and Despeisse, 2016).

1.1 Initial Situation and Research Aim

Generally, an applied research in the area of BM is longstanding, when one compares it with SBM, which is pretty much recent. The applied research on SBM is new, and has already created a rich stream of a research work in its own direction. (Freund et al., 2017; Massa et al., 2017)

For any company, to compete in a disruptive market in the finest way, it is important to focus upon sustainability motivated innovation practices (Paramanathan et al., 2004; Roome, 1994; Schaltegger, 2011). And to encounter todays environmental, social, and economic challenges, companies will need more than new products, processes, and organizational practices. Sustainability-oriented innovation (SOI), which in terms of innovation means, the integration of environmental and social characteristics into new organizational structure, products, and processes (Brundtland, 1987; Klewitz et al, 2014). The term SOI has appeared since 1987(Klewitz et al, 2014). Whereas, the previous research about SOI was often for large firms, but it was the last decade, that truly produced comprehensive data on the specificities of SOI in terms of small and medium sized enterprises (SME; Klewitz et al, 2014).These SME have been gradually recognized as the fundamental contributors to the sustainable development (SD; Klewitz et al, 2014). According to statistics in the year 2017 (provided by the federal ministry of Austria for the digital and economic affairs), SME had approximately the 99.6% share of the total Austrian business economy, which proves that they are the backbone of Austria's economy (SME in Austria, 2020). This reality poses an urgent need for the development of an integrated framework of SBM, that easily highlights unseen opportunities, and engages the collective passion of problem solving in terms of economic, social, and environmental challenges faced by businesses (Ford et al, 2016).

3DP is a broader technology integrating different methods, and has been hailed as the catalyst for the next industrial revolution. The technology has democratized the manufacturing systems (i.e. supply push to demand pull). Companies can achieve a higher level of sustainability in manufacturing via 3DP. Over years, improvement in the 3DP have achieved a progress in terms of cost reduction and speed improvement. The adoption and implementation of 3DP is certainly disrupting the world of manufacturing, and the ways in which companies used to capture the value before. (Ford et al, 2016)

In medical sector, a growth of $12 billion was forecasted by analyst in terms of global market in the year 2018 for 3DP. This was almost an increase of 20% over the year 2017. Many suggest that by the year 2021, the total market for 3DP in health care will reach up to $20 billion having Europe (EU) as its core market. (Deloitte, 2019)

Based on an initial situation, and the research gap identified by earlier works of Geissdoerfer et al. (2018) and Öberg et al. (2018), the aim of this thesis is to contribute to a research of a company's transformation from a conventional BM to a SBM in practice for a 3DP system manufacturer. Therefore, an exploratory study was conducted with HAGE3D, where the main objective was to create a new SBM for their 3DP systems for a medical sector using various tools and frameworks.

1.2 Structure of the Thesis

The thesis consists of four parts having eight chapters in total as shown in Figure 1. Chapter 1 distills the initial situation, and positions a research gap accordingly.

Part 1: Research Intent	Chapter 1; Introduction
Part 2: Theoretical Study	Chapter 2: Sustainability Chapter 3: Sustainable Business Model Chapter 4: 3D Printing Technology
Part 3: Case Study	Chapter 5: The Company HAGE3D Chapter 6: Research Design Chapter 7: Results
Part 4: Concluding Remarks	Chapter 8: Conclusion

Figure 1: Structure of the thesis (own illustration)

The part of a theoretical study systematically summarizes the core chapters i.e., chapter 2, chapter 3, and chapter 4, by reviewing the current literature, in relation to the topic of the thesis. This creates a strong foundation of more clarity and broader understandability on the specific chapters during the phase of desk research. A basic understanding is portrayed in chapter 2 by explaining sustainability, which further includes the subchapters, such as SD and sustainable development goals (SDG). Chapter 3 introduces the concept of SBM, where its subchapters further summarize the concepts of sustainable business model innovation (SBMI), the SBM archetypes (SBMA), the challenges related to create a SBM, and the usage of various tools and frameworks. 3DP is briefly described in chapter 4, and in its subchapters. Subchapter 4.1, subchapter 4.2, and subchapter 4.3 highlight the history, the fundamentals, and the different methods of 3DP, while, subchapter 4.4. ends the theoretical part of the thesis by explaining the pros and cons of a 3DP.

The case study, which is the practical part of the thesis contains three chapters. At first, a brief description about HAGE3D is illustrated by Chapter 5, whereas, chapter 6 explains the detailed research process, and helps as a guiding procedure to conduct the research accordingly. Chapter 7 presents the mains results of the thesis.

The last part of the thesis is about concluding remarks. Chapter 8 concludes the thesis by suggesting the limitations to this study, and gives an outlook for the future work.

THEORETICAL STUDY (PART 2)

2. Sustainability

As stated earlier, in chapter 1, the compelling evidences for rapid climate change (NASA, 2019), have forced all the stakeholders to collaborate in the process of setting new standards, policies, and guidance to enhance sustainability in businesses (Sachs, 2015; Business roundtable, 2019; WEF, 2020). Earth’s climate is changing because of human activities, causing disruptive environmental and social impacts (NASA, 2019). Such impacts will continue to create more potentially unforeseen difficulties in the future. In order to limit and adapt to climate change, more immediate and coordinated actions are needed to protect the global security. These actions must be done smartly, and must involve all the stakeholders i.e. individuals, societies, industries, governments, acting at local, regional, national, and global scales to yield significant economic, environmental, and social benefits (AGU, 2019).

The challenge of climate change, and the concept of sustainability are interconnected. “*Sustainability is something that meets the needs of the present without compromising the ability of future generations to meet their needs*” (Brundtland, 1987). The term, sustainability, in the modern use is comprehensive and hard to define precisely. However, the principle of sustainability is based on three main pillars i.e. economy, society, and environment (Olson, 1996).

The main idea is to show responsibility, while consuming resources in such a way that the planet supports those generations yet to come. Planet earth has limited amount of resources, which are exploited every day to produce various products. The pursuit of sustainability means to create products, and maintain consumption, to support present and future generations, and offers means for generating innovative solutions for economic, social, and environmental challenges. (Rainey, 2006; NASA, 2019)

2.1 Sustainable Development

The concept of sustainability is very important for the today's leading international framework, which is the 2030 agenda for SD, and its SDG (UN, 2019). SD is the core concept for this era, that integrates both i.e., a way of understanding the world, and a way for solving global problems (Sachs, 2015). And the spirit of SD in practice means to solve problems using scientific knowledge, and with morality (Sachs, 2015).

In 1972, the term SD was first used in a conference on the human environment at United Nations (UN; Hall et al., 2010). The chances of transformation towards sustainability acknowledged an inclusive consideration with the Brundtland report (Brundtland, 1987). On an organizational level, the concept of corporate sustainability means, the alignment of environment, and social goals with economic goals of the company (Dyllick and Hockerts, 2002). The purpose of aligning these three types of monetary and non-monetary goals is, to reduce harm, and increase benefits for nature and society (Dyllick and Hockerts, 2002).

When society aims for economic, social, and environmental objectives, this kind of a holistic framework resonates SD. The concept of sustainability analyzed through environmental and social dimensions, constantly provides SD. Three major aspects of SD are economic development, broad-based social inclusion, and environmental sustainability. All these aspects are interlinked and connected to each other in depicting the true meaning of SD. There are certain parts in considering the pathways towards SD i.e. the analytical part and the normative part. By analytical part it is possible to understand the interlinkage of the economy, society, environment, and politics, while normative part is how to act in order to achieve or implement the SDG. (Hall, 2002; Sachs, 2015; Klewitz et al, 2014)

Businesses need SD strategies for preemptive and innovative approaches in order to achieve the long-term outcomes. These SD strategies change the basis for competitive advantages, and seek to create exciting new opportunities for businesses. (Rainey, 2006)

2.2 Sustainable Development Goals

The era of 8 Millennium Development Goals (MDG) came to an end in the year 2015, and the official launch of transformative 2030 agenda for SD was approved by world leaders (UN-MDG, 2015). The new agenda calls on the countries to start efforts to achieve the 17 SDG by 2030 as shown in the Figure 2. All these SDG aim to transform the world by 2030 (Sachs, 2015). The objective produces a set of universal goals that meet the important social, economic, and environmental challenges, that the world is facing (UN, 2015). The UN is working with all the stakeholders, and has galvanized extraordinary efforts to carry on with this ambitious SDG. The participation of the whole world, in terms of problem solving and brain storming, is required in order to accomplish these SDG (Sachs, 2015).

Figure 2: Sustainable development goals (UN, 2015)

GOAL 1: NO POVERTY

People who live without being able to address their basic needs are considered in extreme poverty. These needs include access to health, adequate housing, food and safe water, and education. The goal 1 of no poverty means, to culminate poverty in all its forms across by 2030. (Sachs, 2015; UN, 2015)

The business themes associated with goal 1 are; *"availability of products and services for people on low incomes…economic development in areas of high priority…access to quality essential health care services"* (SDG Compass, 2019).

GOAL 2: ZERO HUNGER

The goal 2 aims, that hunger should be ended by 2030. This goal also aims to end malnutrition, in all its forms, by 2030. This goal can be reached by doing food security, and by promoting sustainable agriculture across the planet. And also, by creating and providing healthy nutrition. (Sachs, 2015; UN, 2015)

The business themes associated with the goal 2 are; *"healthy and affordable food…food labeling, safety and prices…genetic diversity of farmed and domesticated animals…sustainable sourcing…labor practices in supply chain"* (SDG Compass, 2019).

GOAL 3: GOOD HEALTH AND WELL BEING

One of the important indicators of SD is, health, which is also an essential necessity for all human beings. Health is a global problem, where each region of the world faces its own challenges. UN has defined reproductive, maternal, newborn, and child health, as well as mental health, chronic, and infectious diseases as some of the biggest global and regional issues. Progress has been made to achieve this goal, but still there are still considerable amounts of challenges, that still remain. The goal 3 ensures a healthy life, and promotes well-being for all at all ages. It requires from governments, to invest in human resources for health, and to invest in social protection, so that people who need health services can access and afford these services. (Sachs, 2015; UN, 2015)

The themes related with the goal 3 in terms of business are; "*occupational health and safety… access to medicines… access to quality essential health care services… air quality… water quality*" (SDG Compass, 2019).

GOAL 4: QUALITY EDUCATION

The reason to have an education is that it helps individuals to get jobs, helps people to be healthier, and helps societies to be peaceful. In many ways, an access to quality education is the fundamental of all SDG. The goal 4 aims to ensure quality in pre-primary education (which is important for brain development), primary education, secondary education, and advocates that lifelong learning is fundamental for all generations to sustain. (Sachs, 2015; UN, 2015)

The business themes associated with the goal 4 are; *"education for sustainable development… availability of a skilled workforce… capacity building… indirect impact on job creation… youth employment"* (SDG Compass, 2019).

GOAL 5: GENDER EQUALITY

The goal 5 takes the international community to commit not only for promoting but achieving gender equality, and empowerment of female population by 2030. For peaceful, prosperous, and sustainable world gender equality is a must. It is truly a fundamental human right. (Sachs, 2015; UN, 2015)

The business themes associated with the goal 5 are; *"equal remuneration for women and men… diversity and equal opportunity… access to sexual and reproductive health-care services… workplace violence and harassment… women in leadership… childcare services and benefits"* (SDG Compass, 2019).

GOAL 6: CLEAN WATER AND SANITATION

Clean water for drinking is also the most important need of humanity. Worldwide, around 663 million people do not have access to safe water on this planet, and about 2.4 billion people do not have access to safe sanitation. Therefore, the goal 6 focuses on the sustainability of sanitation and water management. (Sachs, 2015; UN, 2015)

The business themes associated with the goal 6 are*; "sustainable water withdrawals… protection of water-related ecosystems and biodiversity…improved water quality through effluent treatment…improved water efficiency through application of 5R principles: reduce, reuse, recover, recycle, replenish… affordable access to water, sanitation, and hygiene for employees and communities… equal, affordable, and safe, access to water access, sanitation, and hygiene for employees and communities"* (SDG Compass, 2019).

GOAL 7: AFFORDABLE AND CLEAN ENERGY

Everyone should access green, safe and cheap energy. The goal 7 is to give people, the basic need of consuming energy so that they should carry sustainable living in terms of households. (Sachs, 2015; UN, 2015)

The business themes associated with the goal 7 are; *"electricity access… electricity availability and reliability… renewable energy… energy efficiency… environmental investments"* (SDG Compass, 2019).

GOAL 8: DECENT WORK AND ECONOMIC GROWTH

This goal aims to reduce the income gap between the poor and the rich to insure economic growth. It truly emphasizes the provision of full employment opportunities, security of labor rights, and total elimination of slavery and human trafficking. (Sachs, 2015; UN, 2015)

The business themes associated with the goal 8 are; *"employment… economic inclusion…non-discrimination…availability of a skilled workforce…elimination of forced or compulsory labor"* (SDG Compass, 2019).

GOAL 9: INDUSTRY, INNOVATION AND INFRASTRUCTURE

Science, technology, and innovation go together, and they are essential for all the three pillars of SD whether its economic growth, social inclusion, or environmental balance. Therefore, the goal 9 advocates for building robust infrastructure, promoting all-encompassing and sustainable development, and encourages innovation. For 21st century, only having infrastructure isn't enough, it must be sustainable and flexible to environmental stresses. (Sachs, 2015; UN, 2015)

The business themes associated with the goal 9 are; *"infrastructure investments… access to financial services…research and development…technological legacies"* (SDG Compass, 2019).

GOAL 10: REDUCED INEQUALITY

Income inequalities are severe, up to 40% of global assets are now controlled by the richest 1% of the world's population, while the poorest half owns just 1%. Therefore, this goal aims not only to lessen income inequality but all other kind of inequalities (related to gender, ethnicity, and disability) within and among countries. The goal 10 also emphasizes on raising a voice for the rights of developing countries at the global institutional level. (Sachs, 2015; UN, 2015; SDG Compass, 2019)

The business themes associated with the goal 10 are; *"availability of products and services for those on low incomes…access to financial services…equal remuneration for women and men…diversity and equal opportunity…economic inclusion"* (SDG Compass, 2019).

GOAL 11: SUSTAINABLE CITIES AND COMMUNITIES

By 2050, the world's population by almost 70 % will move, and start to live in cities. This will make cities critical in attaining sustainable future. Therefore, this goal aims to create cities and human settlements resource-efficient, resilient, inclusive, comprehensive, and maintainable. It also emphasizes the fortification of world's cultural heritage, and reduction of deaths and displacements, which happen due to natural adversities. (Sachs, 2015; UN, 2015; SDG Compass, 2019)

The business themes associated with the goal 11 are; *"access to affordable housing…infrastructure investments…sustainable transportation…access to public spaces…sustainable buildings"* (SDG Compass, 2019).

GOAL 12: RESPONSIBLE CONSUMPTION AND PRODUCTION

The goal is that both consumption and production should include sustainability. The main idea of this goal circulates around the topic of circular economy (to recycle, reuse, and redesign the products that are already used). This goal is about waste management (industrial waste and food waste). (Sachs, 2015; UN, 2015)

The business themes associated with the goal 12 are; *"resource efficiency of products and services…materials recycling…product and service information and labeling…procurement practices"* (SDG Compass, 2019).

GOAL 13: CLIMATE ACTION

Climate change has an impact on all the other SDG. If the issue of climate change is not addressed, it would be either difficult to achieve SDG or, impossible to achieve them. Therefore, the goal emphasizes that urgent steps should be taken to combat the climatic change, and its overall effect. There is a need for the conclusive activities under the UN framework convention on climate change, and to strain upon the decrease of greenhouse gas releases, and the improvement of climate resilience. (Sachs, 2015; UN, 2015; NASA, 2019)

The business themes associated with the goal 13 are; *"energy efficiency…environmental investments…risks and opportunities due to climate change"* (SDG Compass, 2019).

GOAL 14: LIFE BELOW WATER

There are many threats to oceans today that includes ocean acidification, overfishing, loss of ocean and coastal habitats (like coral reefs and mangroves), and water pollution (form nutrients and plastic. Therefore, this goal stresses upon the idea of preserving the oceans and sea life resources. (Sachs, 2015; UN, 2015; NASA, 2019).

The business themes associated with the goal 14 are; *"marine biodiversity…environmental investments…sustainable sourcing…water discharge to oceans…ocean acidification"* (SDG Compass, 2019).

GOAL 15: LIFE ON LAND

This goal call for the idea of caring and reestablishing earthly ecosystems, handling sustainable forests and stumbling biodiversity loss. This vital goal distinguishes all the harmful intimidations to the earthly ecosystems, and biodiversity. (Sachs, 2015; UN, 2015)

The business themes associated with the goal 15 are; *"deforestation and forest degradation…genetic diversity of farms and domesticated animals…land remediation…landscapes forest management and fiber sourcing…mountain ecosystems…natural habit degradation…terrestrial and inland freshwater ecosystems"* (SDG Compass, 2019).

GOAL 16: PEACE AND JUSTICE STRONG INSTITUTION

Businesses grow and succeed in nonviolent environments, where operating costs are foreseeable, and working environments are stable. The goal 16 aims to decrease issues like violence and human trafficking. and advocates good governance, human rights protection, and all fundamental freedoms. (Sachs, 2015; UN, 2015)

The business themes associated with the goal 16 are; *"effective, accountable and transparent governance…compliance with laws and regulations…anti-corruption…public access to* *information…physical and economic displacement…inclusive decision making"* (SDG Compass, 2019).

Goal 17: PARTNERSHIPS TO ACHIEVE THE GOAL

An international collaboration is very significant to attain each of the preceding 16 SDG. This goal promotes the idea to reinforce the means of application, invigorate the global partnership in terms of SD, and countries and companies should support and collaborate with each other. Nevertheless, there is a fear by some that it is not affordable to be on SD path because it might be a compromise on saving humanity at the cost of ending economic progress which makes SDG unrealistic and impossible to be achieved. (Sachs, 2015; UN, 2015)

3. Sustainable Business Model

The world is rapidly changing today. People's awareness about the global problems has significantly gone up with an increased access to the information (due to the power of internet). They are asking questions about the business practices through a socially and environmentally conscious lens. (UN, 2015)

Both, researchers and practitioners have agreed, that the business as usual is rapidly approaching its limits, and needs to become sustainable (Lüdeke-Freund & Dembek, 2017). Minimization of the natural resource consumption, maximization of societal and environmental benefits, and collaboration between all stakeholders are the requirements for tackling the challenges of a sustainable future (Bocken et al., 2013). Today, most of the industries are in the phase of this transformational change, i.e. from a conventional BM to a new SBM as illustrated in the Figure 3.

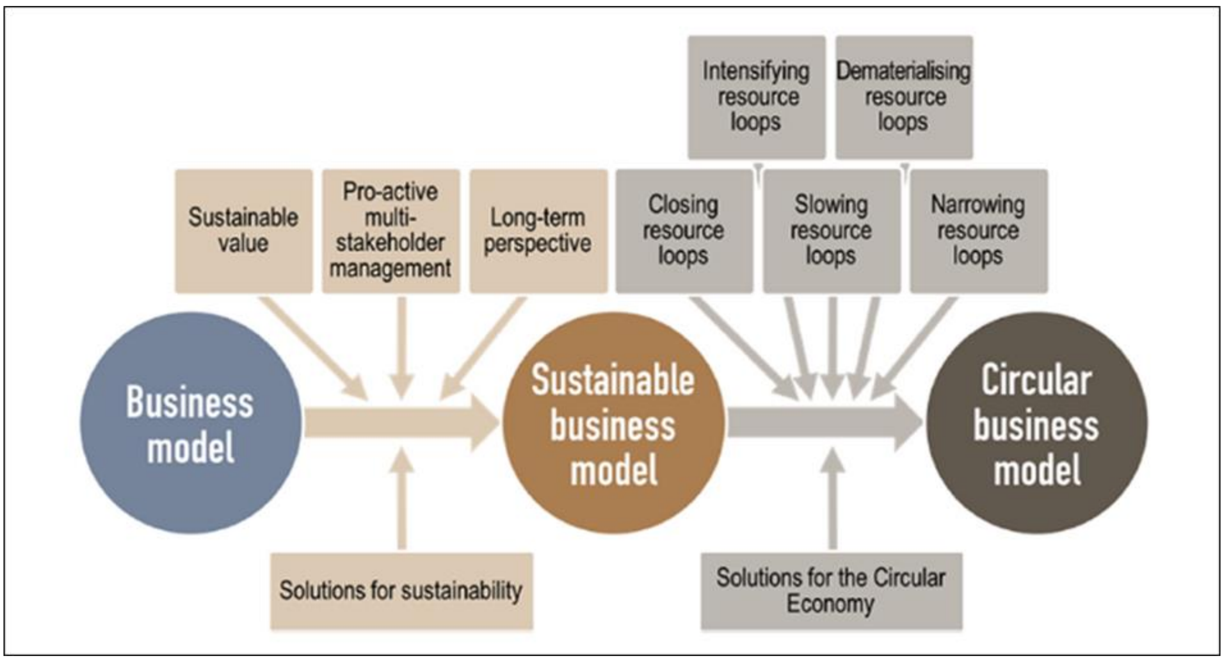

Figure 3: The three kinds of business models (Geissdoerfer et al., 2018)

Business model: Almost every company makes a BM, which outlines the importance of a BM with a missing clarity on how a BM is defined (Chesbrough, 2007). The concept is used for communicating and presenting complex business ideas to the potential investors efficiently, precisely, and with a short frame of time. A BM creates an ease of understanding and clarity between the actors related to a company's business (Zott et al., 2011) with a holistic perspective (Öberg et al., 2018).

Sustainable business model: Today, both academically and practically, a rapid growth of interest on the topic of SMB has been witnessed, which is a transformation from a conventional BM towards more sustainable BM. Certainly, this interest is partially triggered by an external pressure of society, which demands the integration of sustainability in the core principles of companies and institutes. (Geissdoerfer et al., 2018)

Many observations have been presented, that SBM is developing as an integrative field (a field that depends on established fields, and also exceeds them at the same time). Therefore, a dedicated research program is needed to develop a better understanding about SBM. SMB holds a long-term perspective, creating a sustainable value (i.e. monetary and non-monetary) considering stakeholders in a wide spectrum, and a BM that incorporates pro-active multi-stakeholder management. SBM is a key concept to drive and implement innovation in terms of sustainability, and to insert sustainability into the whole array of business processes. (Bocken et al., 2013; Lüdeke-Freund & Dembek, 2017)

Geissdoerfer et al., (2018) present various definitions of SBM, from which one can assume, that the concept of SBM inserts the phenomena of SD (earlier discussed in subchapter 2.1) in all the business activities of a company, and generates ground for optimism, that the companies' implementation of SBM can help in attaining the 17 SDG explained in subchapter 2.2 by 2030. SBM has been conceived as a source of competitive advantage, which helps companies on the market to differentiate themselves from other competitors. SBM has features, which are deeply connected to sustainability principles, in a way that provides an effective contribution to SD. (Michael E. Porter, 2011; Bocken et al., 2013)

Circular business model: Pressure on business by various stakeholders, to operate sustainably, are growing, and have already triggered a new kind of economy, which is circular economy (CE), which will further create a need for a new kind of BM i.e. circular business model (CBM). Such BM, that try to close, slow, intensify, dematerialize, and narrow resource loops in addition to the creation of sustainable value are known as CBM. (Bocken et al., 2013; Geissdoerfer et al., 2018)

3.1 Sustainable Business Model Innovation

Sustainable business model innovation (SBMI) is the process precisely aiming at integrating factors like a sustainable value and an active management of stakeholders in a wide spectrum into the BM (Geissdoerfer et al., 2016). One can present the concept of SBMI by combing the elements of BMI, and sustainability together, which is understood to support sustainable process, product, or service innovations (Boons, 2013).

SBMI labels the creation of new SBM, which can help to develop and combine solution in two ways. First, by reducing negative effects, and second, by creating positive effects regarding environment and society (Schaltegger et al., 2016). SBMI can be attained by finding the value uncaptured in present BM or SBM, and later turning this new understanding into value opportunities. By doing so a new BM with a more sustainable value can be attained easily (Yang et al., 2017).

Types	Description
1) Sustainable start-ups	A new organization with a new SBM is created
2) SMB transformation	The current BM is changed, resulting in a new SBM
3) SBM diversification	Without major changes in the existing BM of the organization, and additional, SBM is established
4) SBM acquisition	An additional, SBM is identified, acquired, and integrated into the organization

Table 1: An overview of various types of sustainable business model innovation (Geissdoerfer et al., 2018)

Table 1 illustrates, four types of SBMI types, which mainly depends on the purpose, situation, and need of creating a new SBM by a company. Startup, transformation, diversification and acquisition are the keywords used, to differentiate these four SBMI types (Geissdoerfer et al., 2018).

3.2 Sustainable Business Model Archetypes

Groupings of mechanisms and solutions which contribute to build up the SBM are called sustainable business model archetypes (SMBA). The focal purpose of these archetypes is to create a shared language, that can be applied to fast-track the creation of a SBM in research and industry. During a practical approach (i.e. workshop), where various tools are used, it’s the typology of SBMA, that assists participants in seeking new ways to create sustainable value, and to tackle the demands of various stakeholders that are conflicting. Furthermore, the archetypes also simplify learning from cross-industry perceptions. (Short et al., 2012; Bocken et al, 2013)

Sustainable Business Model Archetypes
1. Maximize material and energy efficiency (Do more with less resources, generating less waste, emissions and pollution) **2. Create value from waste** (Turn waste streams, emissions, and discarded products into feed stocks for other products and processes, and make best use of under-utilized capacity) **3. Deliver functionality, rather than ownership** (Provide services that satisfy users’ needs without having to own physical products) **4. Encourage sufficiency** (Solutions that actively seek to reduce consumption and production) **5. Adopt a stewardship role** (Proactively engaging with all stakeholders in long-term) **6. Re-purpose the business for society/environment**

(Focusing the business on delivering social and environmental benefits, rather than economic profit maximization)
7. Integrate business in the community
(Integrating business back into local communities through employee ownership and collaborative approaches to business)
8. Develop scale-up solutions
(Delivering sustainable solutions at a large scale to maximize benefits for society and the environment)
9. Radical innovation
(Introduce system change through introduction of radical new technologies to facilitate a greener economy)

Table 2: Various types of Sustainable business model archetypes (Bocken et al., 2013)

Table 2 illustrates the 9 types of SBMA. The grouping of these SBMA are based on technological, social, and organizational perspectives, having various examples (Bocken et al., 2013).

Technological grouping of SBMA

The SBMA 1 (i.e. to maximize material and energy efficiency), and SBMA 2 (i.e. to create value from waste) have strong technological perspectives. 3DP, lean manufacturing, low carbon manufacturing and solutions, and dematerialization (of products/packaging) are few examples of the SBMA 1, while circular economy, sharing of assets, and cradle-2-cradle designing are the examples of the SBMA 2. (Bocken et al., 2013)

Social grouping of SBMA

The SBMA 3 (i.e. to deliver functionality rather than ownership), SBMA 4 (i.e. to encourage sufficiency), SBMA 5 (to adopt a stewardship role), and SBMA 7 (to integrate business in community) present solid social perspectives. Product-oriented (PSS-maintenance), use-oriented (PSS-rental, lease, and shared), and result-oriented (PSS-pay per use) are examples of the SBMA 3, whereas the SBMA 4, examples would be i.e., product longevity, demand management (including cap and trade), and consumer education (models for communication and awareness). The SBMA 5, considers examples like biodiversity, consumer care, ethical trade, and radical transparency about social and environmental impact. (Bocken et al., 2013)

Organizational grouping of SBMA

The SBMA 6 (i.e. to repurpose the business for society and environment), SBMA 8 (i.e. to develop scale-up solution), and SBMA 9 (radical innovation) highlight stronger organizational perspectives. The SBMA 6 examples are i.e., social enterprise (for profit), home based flexible working, etc. while combined and cooperative approaches, open innovation (platforms), and models that support entrepreneur are the examples of the SMBA 8. (Bocken et al., 2013)

The SBMA are regarded as the starting point for developing a SBM. They define a clearer research purpose of a SBM, and provide foundation to de-risk the SBMI process. (Bocken et al., 2013)

3.3 Sustainable Business Model Challenges

Understanding the value created by a company is not simple as it is very difficult to depict all the value outcomes of the business activities (Geissdoerfer et al., 2018). This subchapter describes the challenges, related to the process of SBMI. Factors like globalization, climate change (global warming), and new policies and regulations increase the pressure on companies to survive and compete in long run. According to Geissdoerfer et al., (2018), there are various challenges, that companies encounter during the adoption and modification of SBM as shown in Table 3 below.

Challenges	Description
Triple Bottom Line	The co-creation of profits, social and environmental benefits and the balance among them are challenging for moving towards SBM.
Mind-set	The business rules, guidelines, behavioral norms and performance metrics prevail the mind-set of firms and inhibit the introduction of new BM.
Resources	Reluctance to allocate resources to BMI and reconfigure resources and processes for new BM

Technology Innovation	Integrating technology innovation with BMI is multidimensional and complex.
External Relations	Engaging in extensive interaction with external stakeholders and business environment requires extra efforts.
Methods and Tools	Existing business modelling methods and tools, e.g. Osterwalder and Pigneur (2010) and Johnson et al. (2008), are few and rarely sustainability driven.

Table 3 : The challenges related to the creation of a sustainable business model (Geissdoerfer et al., 2018)

Organizations gradually recognize that fulfilling their sustainability motivations does not only require new technologies, but innovation on the BM level. (Rashid et al., 2013; Geissdoerfer et al., 2018)

3.4 Overview of Related Tools and Frameworks

The conventional business modelling tools and frameworks are limited in terms of usage, in order to translate the research of SBM. Therefore, a range of innovative tools and frameworks have been established that can support the creation and application of BM and SBM. These tools and frameworks are practical resources, helping companies to organize and deliver long term sustainable change. (Geissdoerfer et al., 2018)

Following are some of the tools and frameworks that are currently in practice:

Stakeholder Map:

A stakeholder map is a tool, that supports a company in identifying and representing relevant stakeholders (Fassin, 2009).

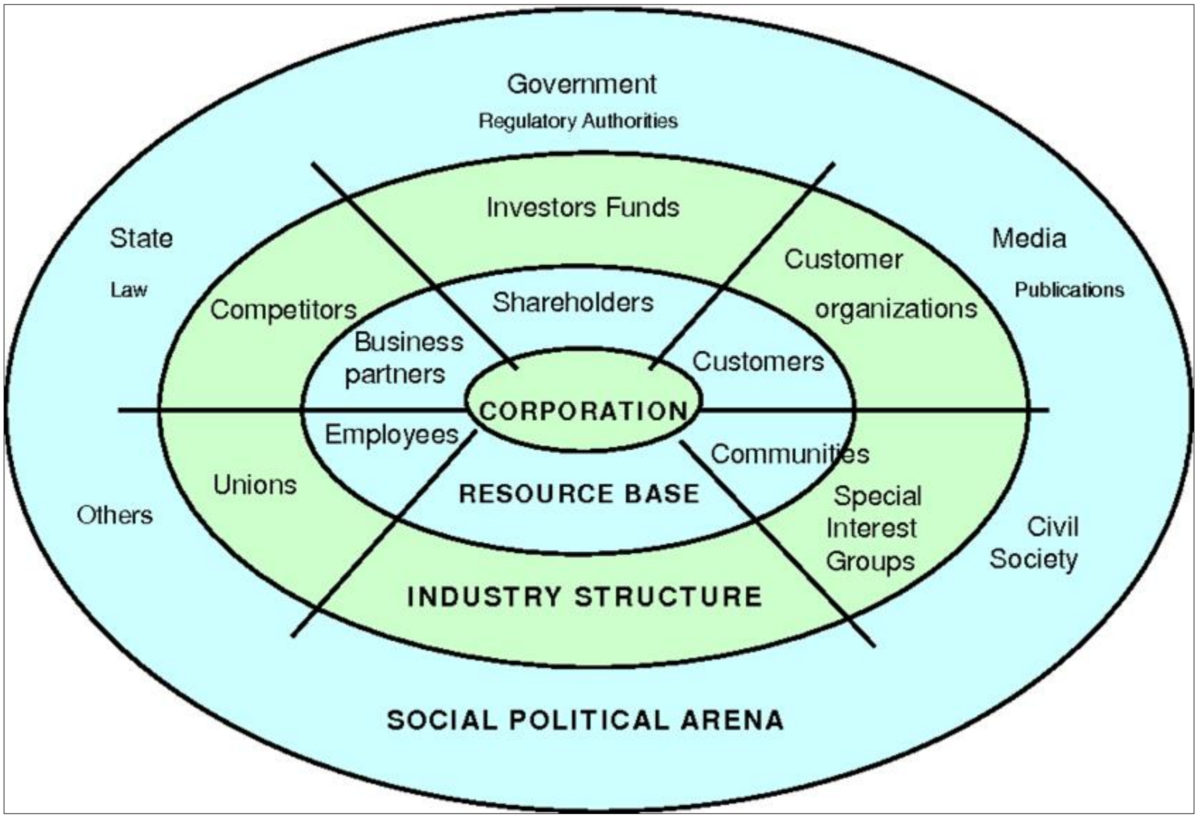

Figure 4: A stakeholder map based on (Fassin, 2009)

The upgraded and refined version of a stakeholder map is shown in Figure 4, with small improvements, that is like Freeman's inventive model (1984). It consists of three layers, including the resource base as an inner layer with other two layers focusing general stakeholders of the industry, and the stakeholders in social and political arena. The tool is applicable to all the companies, from exploring the stakeholders assisting in designing BM of established or new companies, and aims to focus business modelling regarding sustainability by supporting companies to identify and position all relevant stakeholders in the business. (Fassin, 2009)

Value Mapping Tool:

A VMT assist companies in creating a sustainable value during the process of business modelling i.e., a tool used for embedding sustainability into business modelling (Bocken et al., 2013). It supports more than eliciting failed value exchanges among multi-stakeholders in the company's network in a systematic visual approach i.e., support value innovation (Breuer & Lüdeke-Freund, 2017). VMT also helps in identifying the captured and failed value linked to the product or service developed and offered by a company (Bocken et al., 2013).

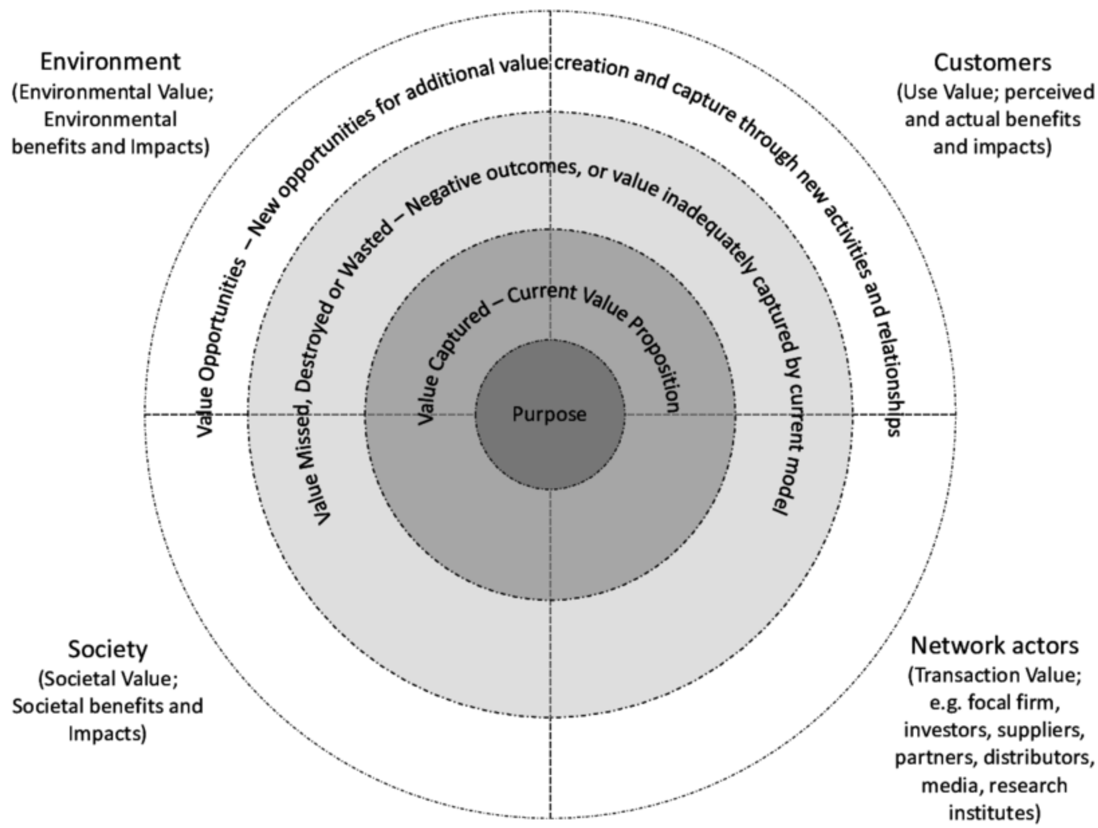

Figure 5: A value mapping tool based on (Bocken et al., 2013)

Figure 5 illustrates a VMT, which is used to generate the opportunities for sustainable value creation. First, the users are required to identify the purpose of its usage. Afterwards, the value is mapped (i.e. value captured, value destroyed, and value missed) with respect to the four dimensions, which are customers, environment, society, and network actors. Finally, the solutions for sustainable value creation can be generated using a VMT. (Rana, 2010)

Collaborative Business Modelling (CBM)

The CBM is a BMI framework, that facilitates the processes of scheduling, implementation and decision-making. This framework is helpful in a situation, that has a high level of uncertainty and complexity. The CBM also provides the opportunity to co-create BM, and value networks that are operated jointly by various stakeholders. (Rohrbeck et al, 2013; Breuer and Lüdeke-Freund, 2017)

Business Model Canvas

Osterwalder and Pigneur (2010) have presented the BMC, which helps to create a holistic view on the BM of a company. Figure 6 shows the following nine components of the BMC:

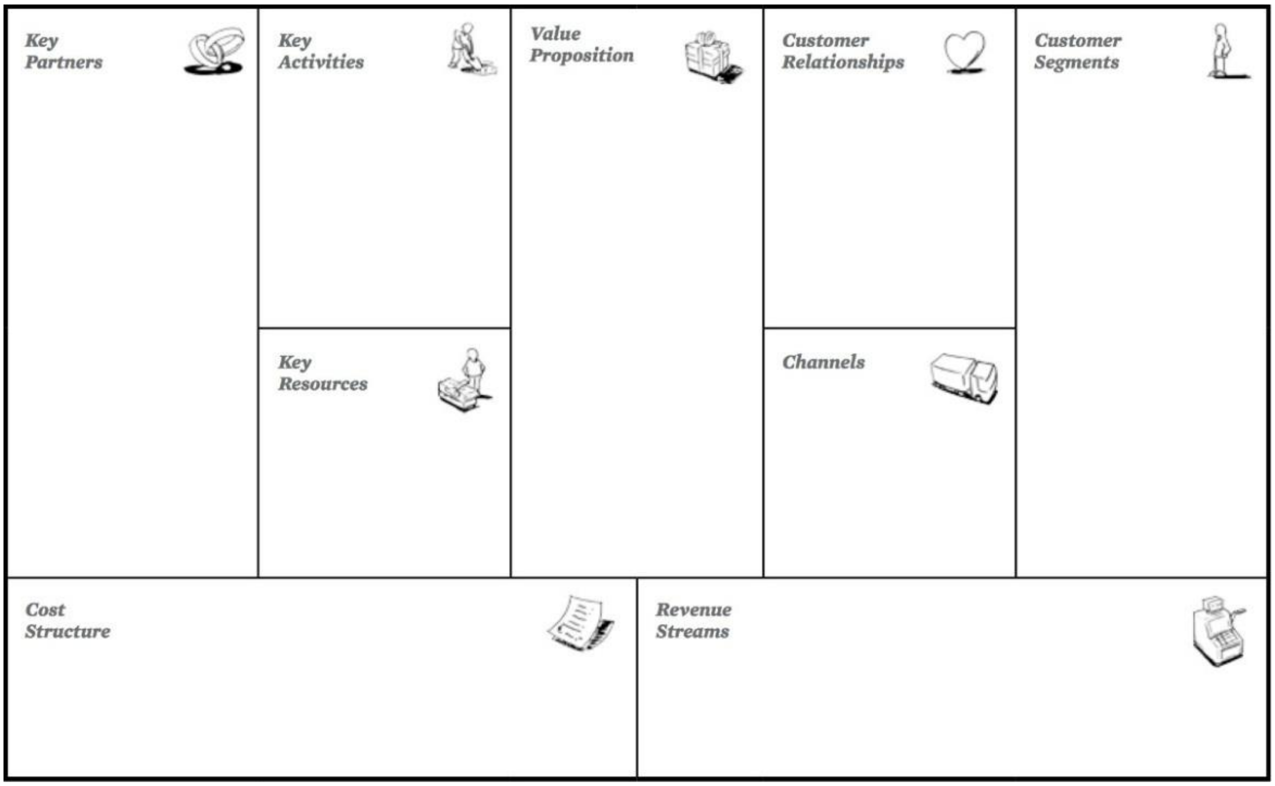

Figure 6: A business model canvas based on (Osterwalder & Pigneur, 2010)

Customer Segments: The BMC (Osterwalder & Pigneur, 2010) describes the customer segments from a sales perspective of a business. The descriptions of customer segment describe the portion of the market company targets to reach (Öberg et al., 2018).

Value Proposition: It reflects how the company's offering (in the form of a product or a service) is put forward to their customer, that are then to decide their value (Öberg et al., 2018). This value could be both quantitative and qualitative i.e. performance, design etc. It is an important instrument for company's survival and success (Osterwalder & Pigneur, 2010).

Channels: The descriptions of channels showcase the understanding of how the customers are reached (such as online, independent retailers, etc.). Through channels, company delivers their value proposition to their customers (Osterwalder & Pigneur, 2010; Öberg et al., 2018).

Customer Relationship: Something that defines the relationship between customers and a company reflecting how resale functions (Osterwalder & Pigneur, 2010; Öberg et al., 2018).

Key resources: They are the means i.e., human, financial resources, knowledge, or a physical asset that any business needs to deliver performance (Osterwalder & Pigneur, 2010).

Key Activities: They describe the action taken to achieve value proposition that can be further categorized into production, problem solving and networks (Osterwalder & Pigneur, 2010).

Key Partners: They are the external actors needed by a company to achieve key activities and value delivery to the customers (Osterwalder & Pigneur, 2010).

Revenue Stream: It could be the way how a business converts the value proposition into financial gain, and reflects structures of outflows and monetary deals with customers (Osterwalder & Pigneur, 2010; Öberg et al., 2018).

Cost Structure: This depicts all kinds of costs such as variable costs, fixed costs, etc. created due to the company operations (Osterwalder & Pigneur, 2010; Öberg et al., 2018).

Triple Layered Business Model Canvas

The Triple Layered Business Model Canvas (TLBMC) is a tool, proposed by Joyce and Paquin (2016), that adds a second layer and a third layer to the Osterwalder and Pigneur's (2010) BMC. The structure approach helps companies, interested in innovating their BM to create, deliver, and capture economic, environmental, and social forms of value in a unified manner. The second layer of TLBMC has nine environmental elements based on the perspective of a lifecycle, and follow that approach, while the third layer of TLBMC has nine social elements based on the perspective of stakeholders, follows that approach. (Joyce & Paquin, 2016; Lüdeke-Freund & Dembek, 2017)

The TLBMC supports companies on the journey of transformation towards a sustainable business. The three layers help to examine the economic, social and environmental aspects of a business, and also its impacts on economy, society, and environment. This is achieved by classifying a value preposition, social value, and functional value of a business in the three layers of a TLBMC. It is, indeed, a tool, that can be helpful, to create a SBM. (Joyce & Paquin, 2016)

Value-Based Network

In order to become sustainable, a company requires new values (Breuer & Lüdeke-Freund, 2017). These values need to be introduced and integrated in a company's organizational structure, and also in its stakeholder's network (Breuer & Lüdeke-Freund, 2017).The Value-Based Network (VBN) by Biem & Caswell (2008) is a framework that facilitates the modelling of a network, that involves a wide range of stakeholders, and depicts shared values by integrating multiple shareholders' outcomes expectations. The VBN framework (Biem & Caswell, 2008) considers both, the subjective and normative values of the stakeholders, which are not considered by VMT and CBM frameworks. It supports innovations of the different kinds i.e., a value innovation, a BMI, and a network innovation with a tool and process (Breuer & Lüdeke-Freund, 2017).

There is also the advanced multi-layered VBN framework developed by Vorraber and Müller (2019), that supports the creation of a SBM, especially by focusing and analyzing the ethical, social, and environmental aspects of the business.

4. 3D Printing Technology

A few years ago, 3DP (or additive manufacturing) was considered as a niche technology. It was a period when this technology was only available to a small segment in the manufacturing industry. As the time passed on, interest in this field developed, and by now this technology is not only accessible, but is also employed by a wide range of industries world-wide. (Redwood, 2019)

This chapter begins with elaborating the history of 3DP. Furthermore, it will review the steps required in the generic process of 3DP and will explain the different types of 3DP methods, which are of utmost relevance in the present-day technological period. The last part of the chapter addresses the pros and cons of 3DP to further consolidated a broad understanding on the topic.

4.1 History of 3DP

The process of fostering innovation and helping people to think analytically demands for the term, “history”, and makes it as important as science and engineering (Dunant, 2012). This subchapter gives a brief tour through the history of 3DP. Since its invention, 3DP has advanced at a speedy pace, with substantial impact in both the industrial and commercial world (Su & Al'Aref, 2018).

Figure 7 depicts almost 40 years of 3DP history in the three stages, which are infancy, adolescence, and prime (Goldberg, 2018).

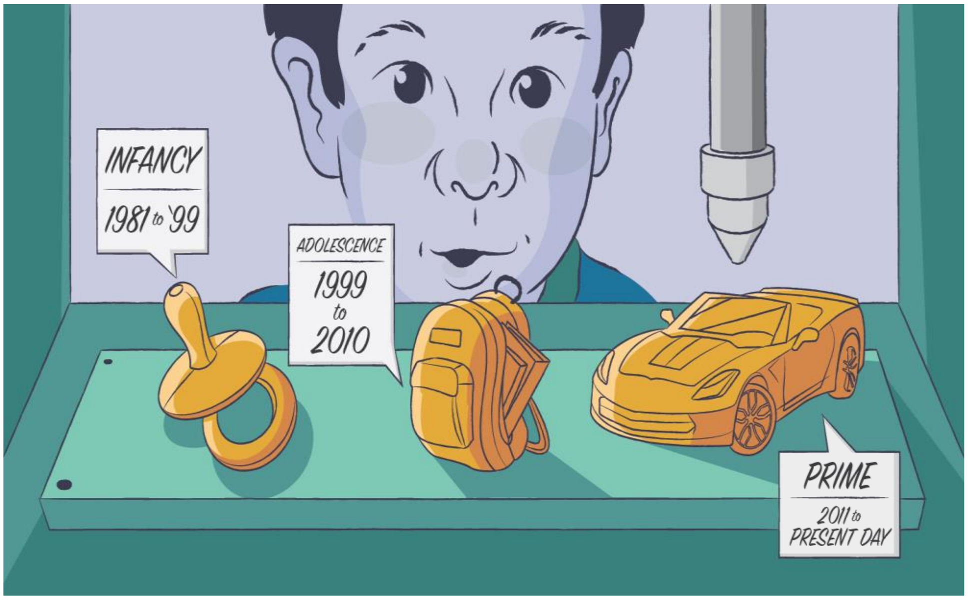

Figure 7: The history of 3D printing (Goldberg, 2018)

Stage 1: The Infancy history of 3DP (1981–1999)

One of the pioneers, who, using a single laser beam, developed a rapid prototyping technique was Hideo Kdama of Nagoya Municipal Industrial Research Institute (Japan). In 1981, Mr. Kdama published for the first time, a work related to photopolymer rapid prototyping system. After three years, in 1984, Charles Hull invented stereolithography (SLA), which is a process in which liquid polymers are hardened under Ultraviolet (UV) light forming cross-sections of a 3D model. (Su & Al'Aref, 2018)

In 1991, Stratasys[1] produced the first fused deposition modelling (FDM) machine in the world. Later in 1992, 3D systems[2] (Charles Hull's company) produced the first SLA 3DP machine. That same year, a startup known as Desk Top Manufacturing (DTM) corporation, produced selective laser sintering (SLS) machine. This machine was similar to SLA technology. Somehow, the main difference was that it used powder (and laser) instead of liquid (and UV light). However, all these technologies were in their infancy, which were far from perfect. There were still many problems,

[1]https://www.stratasys.com

[2] https://www.3dsystems.com

such as distortion (that happens once the material gets hard), and the cost of machines were also high. (Goldberg, 2018)

Stage 2: The Adolescent history of 3DP (1999–2010)

In 1999, the first 3DP organ was implanted in human which was printed by scientists at Wake Forest Institute for Regenerative Medicine (USA). The Scientists achieved to cultivate organs from cells of a patient. This was a great decade in the history of 3DP for medical purposes as scientists from diverse institutions and startups made-up a functional miniature kidney, constructed a prosthetic leg of structural complexity, and the first blood vessels were bio printed, using only human cells. (Goldberg, 2018)

In 2005, the patent for Stratasys'[3] FDM technology expired, and subsequently two open source projects (the RepRap Movement and Fab@ Home) started. The goal of both the projects was to develop and share designs for a 3DP system that was affordable to many individuals. (Su & Al'Aref, 2018)

In 2006, 3DP startup Objet[4] (now merged with Stratasys) built a 3DP system that could print in multiple materials, allowing a single part to be made-up in different versions, with diverse material properties. A collaborative co-creation such as Shapeways[5], a website market for 3D models was launched in 2008. The same year, MakerBot[6] hit the scene by launching a website for free 3D (and other models) file sharing. (Goldberg, 2018; Avplastics, 2019)

Stage 3: The history of 3DP in its prime (2011–Present Day)

3DP was an industry initially dominated by a few large firms i.e. the two original companies, 3D Systems[7] and Stratasys[8]. However, in 2011, Ultimaker[9] (company established in Geldermalsen, Netherlands) released their first 3D printer model (made from lasered plywood), which was a

[3] https://www.stratasys.com

[4] https://www.stratasys.com/3d-printers

[5] https://www.shapeways.com

[6] https://www.makerbot.com

[7] https://www.3dsystems.com

[8] https://www.stratasys.com

[9] https://ultimaker.com

straight hit with 3DP enthusiasts. In 2014, NASA[10] made the announcement, that a 3D printer was used in space by them, with the help of which, the first 3DP object was developed in space. This started a new era of manufacturing in terms of space industry. 2014 was another big year regarding the expiration of 3DP patents. The major selective laser sintering (SLS) patent was expired in 2014, letting companies like Sintratec[11] and Formlabs[12] to create less expensive SLS 3D printers. In 2015, metal 3DP technology also got the spotlight when Desktop Metal[13] (the company which is now valued at over $1bn) was founded. Investors in Silicon Valley demanded to invest in the company's technology, i.e. Bound Metal Deposition (BMD). This is because, by comparing their 3D printers with alternative printers, it proved that metals were printed 10x cheaper using their 3D printers. (3dsourced, 2020)

In late 2016, GE Additive[14] was incorporated by GE[15] (the multinational giant). This was possible by acquiring metal 3DP giant companies Arcam[16] and Concept Laser[17]. Two years later, HP[18], in 2018, announced a move to target 3DP market, providing full-color 3D printers based on refining their patent multi jet fusion (MJF) 3DP technology. The technology was applied in combination with an industrial 3D printer at a much lower price compared to other competitors in the market. The very exciting prospect of 3DP occurred when companies like Apis Cor[19] and WinSun[20] jumped in, and created a huge concrete 3D printer to offer a solution for the growing housing crisis. In 2019, Apis Cor[21] built a house in 24 hours and managed to construct a huge 3D printed building in Dubai. Reports project 3DP in construction to be worth $40bn by 2027. (3dsourced, 2020)

[10] https://www.nasa.gov

[11] https://sintratec.com

[12] https://formlabs.com

[13] https://www.desktopmetal.com

[14] https://www.ge.com/additive/

[15] https://www.ge.com

[16] https://www.ge.com/additive/who-we-are/about-arcam

[17] https://www.ge.com/additive/who-we-are/concept-laser

[18] https://www8.hp.com/us/en/printers/3d-printers.html

[19] https://www.apis-cor.com

[20] www.winsun3d.com

[21] https://www.apis-cor.com

In the future, 3DP is likely to have a great impact on healthcare, construction, and manufacturing industries (Su & Al'Aref, 2018). The price of 3DP systems have fallen, and the accuracy of such systems have improved, which gives the innovators an opportunity to push the limits in ways that Charles Hull could have only dreamed of (Goldberg, 2018).

4.2 Fundamentals of 3DP Process

The focus here highlights the general process from a design to the final part. The general process of 3DP does not change, whether the final part is a quick prototype or a final functional part. The process includes the direct conversion of 3D computer- aided design (CAD) data into physical substances, which involves a number of stages. Figure 8 depicts all stages of a 3DP process, which are further explained in more detail. (Gibson et al., 2010; Coykendall, 2014; Awand et al., 2018)

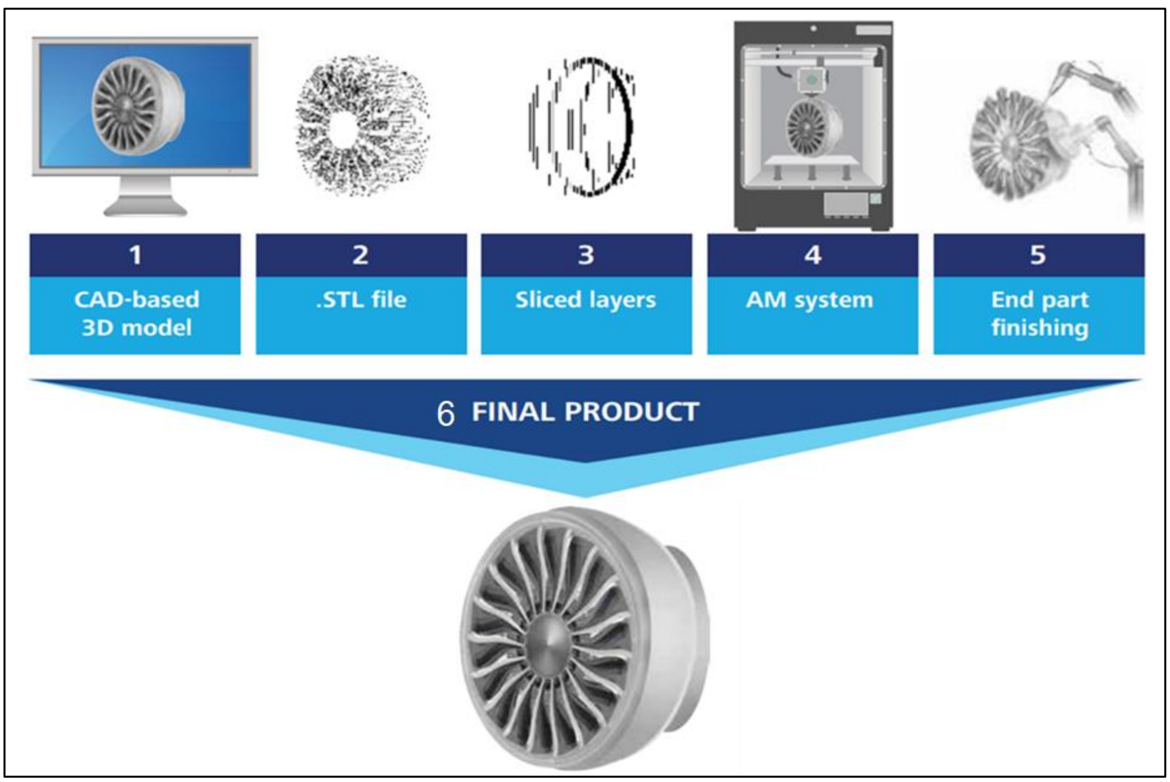

Figure 8: Various steps of the 3D printing process adopted from (Coykendall, 2014)

1. **CAD -based 3D model**

All parts that have to be 3D printed should be styled and designed digitally with an appropriate CAD software, either in the form of 3D solid or surface model. Reverse Engineering (laser scanning) can also be used to get the CAD-based 3D model of an existing product. The software can also be used to analyze the behavior of the object under certain condition by creating virtual simulations using scientific data. (Gibson et al., 2010; Awand et al., 2018)

2. **.STL file**

The conversion of CAD files into standardized .STL files is an important step in process flow of 3DP process. The .STL file format consists of a triangular mesh, that shows the geometry surface of the part in a 3D cartesian space. (Gibson et al., 2010; Awand et al., 2018)

3. **Sliced layers (Data transfer to 3DP system and STL file manipulation)**

As the .STL file is generated by user, the data is transferred to the computer that controls the 3DP system, and possesses the required setup properties. The slicing software is used to convert the 3D surface geometry defined by the .STL file into 2D layers. In short, in this step; the size, position, and orientation are checked and determined. (Gibson et al., 2010; Awand et al., 2018)

4. **AM System (setup)**

AM (or 3DP) system must be properly setup in order to get a good result. The proper setup means setting the parameters of a 3D printer, such as, build volume, build plate temperature, printing speed, nozzle temperature, filament diameter, nozzle diameter, origin and XY offsets to appropriate values, depending on the printing technology, used material and model to be built. This setup is done through a software. (Gibson et al., 2010)

5. **End part finishing**

Pre-adjusted 3DP system parameters mainly define the building process of the part. It is an automated process, but cautious monitoring of the 3DP system is needed with the purpose to ensure, that no mistakes occur during this stage of the process. And as a result, the end part is 3D printed. (Gibson et al., 2010)

6. **Final product**

After the completion of the fifth stage, the final part or product is removed safely from the 3DP system. It is recommended to take specific precautions, while removing the part as to avoid any damage to the manufactured part, i.e. the operating temperature should be sufficiently low etc. (Gibson et al., 2010)

4.3 Methods of 3DP

3DP is a broader technology that incorporates multiple methods. Over the previous decades, the number and variety of 3DP methods have been expended significantly (Awand et al., 2018). Every 3DP method has its advantages, and limitations. Each of the method is more appropriate for certain applications than others (Varotsis, 2019).

This section introduces the 6 most common and prominent methods of 3DP. The following methods are illustrated in the Figure 9, which takes into account the processes according to the underlying physical mechanism on which the 3DP methods operates. (Awand et al., 2018; Perrot and Amziane, 2019)

	Material extrusion	VAT Photo-polymerization	Material Jetting	Powder Bed Fusion	Direct Energy Deposition	Sheet Lamination
Scheme						
Process	Layer by layer deposition of molten material	Selective curving of photo-curable material in a liquid container	Material deposition and subsequent curving	Fusion of powder in a bed by melting the selected region	Direct fusion of the material	Bonding of the individual sheets of material

Figure 9: The 3D printing methods based on (Perrot and Amziane, 2019)

4.3.1 Material Extrusion

Material extrusion method is commonly used in manufacturing and industrial settings. The method pushes the material through a nozzle bounding to previous layers before solidifying to build the 3D part as shown in Figure 9. The material in use, is liquified in a heat chamber and is commonly in the form of a filament. Fused deposition modeling (FDM), which is also known as Fused filament fabrication (FFF), is an example of material extrusion. (ISO/ASTM, 2015; Redwood, 2019; Siemens, 2019)

Fused Deposition Modeling (FDM): FDM is the most widespread, well-established, and a relatively user friendly 3DP method for the desktop 3D printers. A wide variety of materials can be used, including 3DP of multiple-material part by FDM. (Awand et al., 2018)

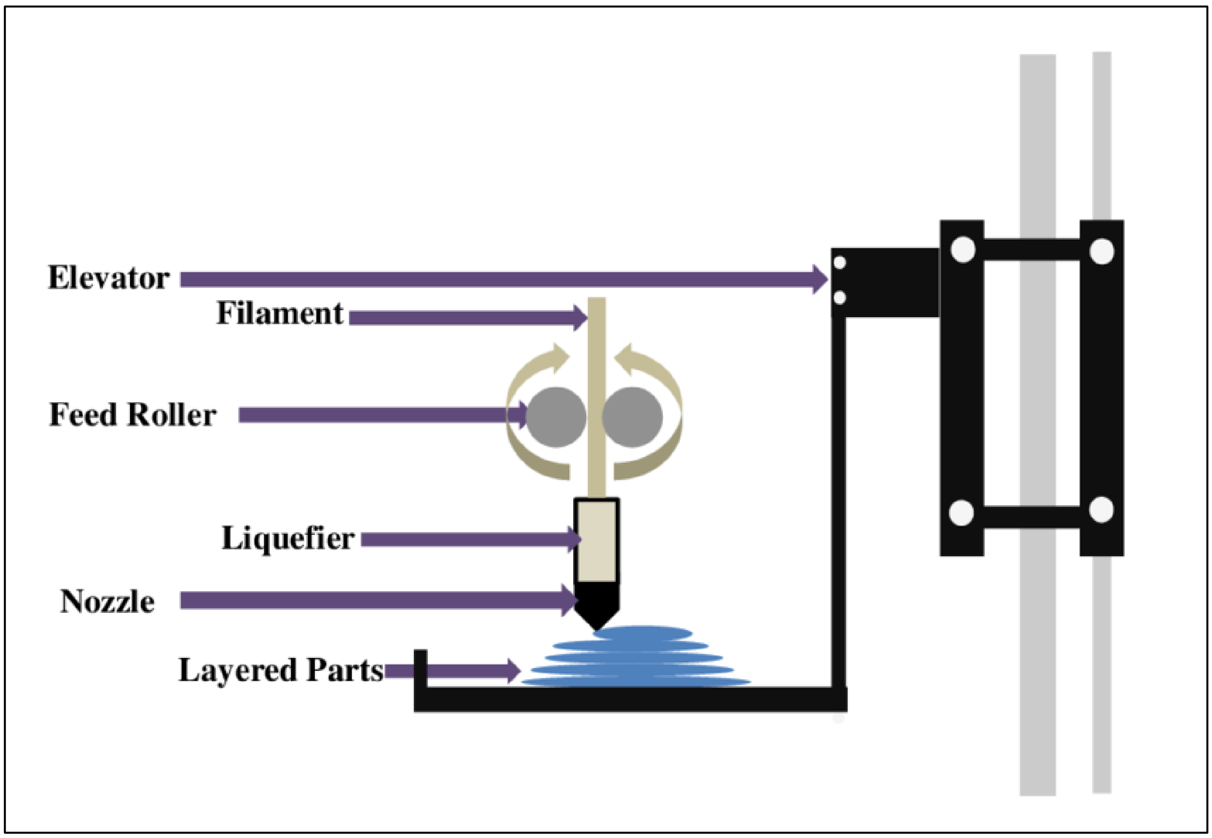

Figure 10: The printing principle of fused deposition modeling based on (Zhang et al., 2015)

As shown in the Figure 10, the method involves the extrusion of thermoplastic (in the form of a filament in a layer by layer fusion), where parts are built from the bottom up. Thermal considerations are very important while setting the temperature of the 3DP system's nozzle (Zhang et al., 2015). The process is most accessible because of low-cost feedstocks, and simple operating conditions (for 3D desktops). Also, industrial FDM can be adopted to a wide variety of thermoplastics similarly used in injection molding. And it can be used for industrial purposes, such as making of ducts for rockets and aircraft. In fact, companies like Airbus or Boeing manufacture planes, having hundreds of parts made by FDM. (Hart, 2019)

FDM is used mostly for the purpose of prototyping, and producing customized parts. And the method is also used in the entry level of 3DP experimentation for biologically relevant material. (Awand et al., 2018; Redwood, 2019)

4.3.2 Vat Photopolymerization

This 3DP method involves the solidification of a liquid photosensitive resin by selectively exposing it to radiation, normally ultraviolet (UV) light as shown in Figure 9. The process of solidifying the liquid resin is called photopolymerization. A platform moves the object vertically to expose new material for each new layer added to the model. In Vat Polymerization an additional structure is required as the liquid resin does not provide enough support for overhang in the solidified part. The photopolymerization is irreversible process. That means there is no way to convert the manufactured 3D parts back to their liquid form, i.e. when heated again, 3D parts will burn instead of melting. This is because the materials that are manufactured are made of thermoset polymers. (Redwood, 2019; Perrot and Amziane, 2019)

Vat Polymerization method is brilliant at producing 3D parts with fine details i.e., high dimensional accuracy, and smooth surface finish, making the method ideal for jewelry, and many medical applications. On the other hand, the brittleness of the 3D parts produced by this method is a matter of concern, and its limitation. SLA was the first Vat Photopolymerization method developed. (Redwood, 2019)

Stereolithography (SLA or SL)

The SLA method was invented by Chuck Hall in 1980s, which has recently gained high popularity in terms of its application. The method as shown in Figure 11 involves using a UV laser, directed by mirror galvanometers, to scan across a bath of liquid- material (photo-resin). A platform moves after each layer, and a recoated blade moves across the resin to create a smooth surface. The process repeats until a solid part is produced. (Konta et al., 2017)

Finally, to improve mechanical properties, the 3D printed part is typically post-cured, with the usage of UV light (Hart, 2019; Redwood, 2019).

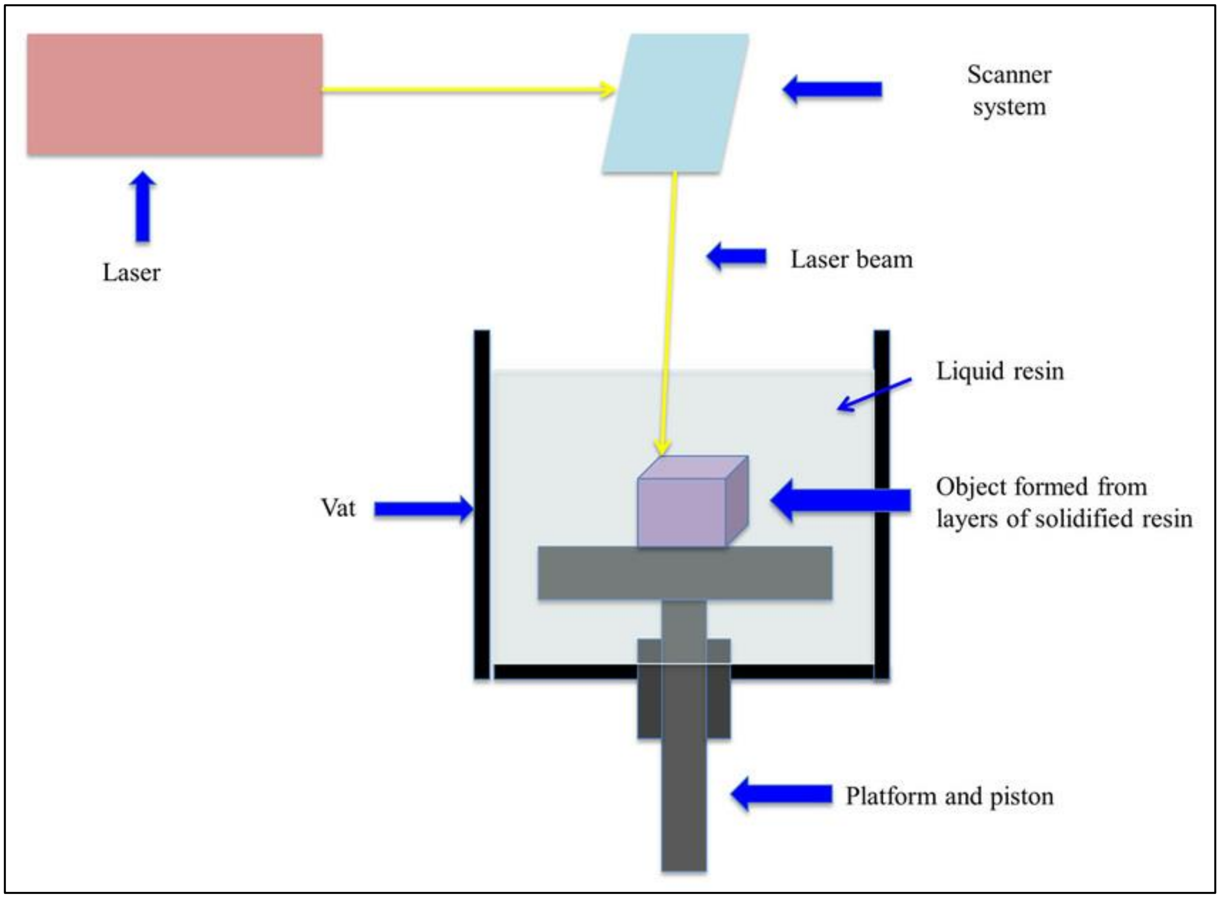

Figure 11: The printing principle of stereolithography based on (Konta et al., 2017)

The problem with SLA produced parts is that their mechanical properties and visual appearance degrade overtime when they are exposed to sunlight. Another limitation is, that a support structure is always required during this method. However, the method is ideal in the creation of visual prototypes. (Redwood, 2019)

4.3.3 Material Jetting

Material jetting is a general class of 3DP method, which uses inject technology to deposit droplets of material (liquid resin). This method often gets compared with the method of 2D ink jetting. As shown in Figure 9, the droplets of material are selectively deposited via inkjet-style printheads, which are then solidified by UV light exposure in the process of building a solid 3D object. The nature of the method requires a support. During the build, this support also printed beside the main 3D part, using a dissolvable material. Post-processing this support is removed easily. (Perrot and Amziane, 2019; Redwood, 2019; Siemens, 2019)

There isn't a high difference between the method of Material jetting and Vat Photopolymerization. Material jetting uses printheads to distribute resin while instantaneously curing it, whereas, Vat Photopolymerization works somehow similarly by selectively curing liquid photopolymer resins in a holding tank with light. (Siemens, 2019)

In terms of precision, material jetting is considered in the list of the precise methods of 3DP. This method is capable of printing in layers less than 20 microns thick. And is also known for building CAD designs with fine details, high accuracy, and smooth surfaces making it favorite for realistic models, visual prototypes, tooling, and casting. The method also provides a freedom to the designer. This freedom is in terms of the usage, i.e. the usage of different colors and materials in one print, However, the drawbacks connected with material jetting are in terms of cost and mechanical properties. The method has high cost, and the mechanical properties associated to the UV stimulated photopolymer are brittle. (Redwood, 2019; Siemens, 2019)

4.3.4 Powder Bed Fusion

Powder Bed Fusion (PBF) is another type of a 3DP method. This method uses a heat source to produce a solid 3DP part. A heat source could be a laser, an electron beam, or an infrared heater. Figure 9 shows the layer by layer fusion of the particles, that can be plastic powder particles, or metal powder particles. Various methods of PBF can be subcategorized on the basis of energy sources (laser or electron beam), and the powder used in the methods (plastic or metal). Selective laser sintering (SLS) and selective laser melting (SLM) are the main subcategories of PBF. (Awand et al., 2018; Redwood, 2019; Perrot and Amziane, 2019)

Selective Laser Sintering: SLS is in the subcategory of PBF as shown in the Figure 12. The method is very similar to SLA, as it also uses scanning laser, but the laser here however is of much higher power. The principle method of SLS is based on the laser sintering of powder (polymers), where the powder is preheated before melting point. And then the laser melts the powder (less energy needed for the laser as the powder is preheated). (Awand et al., 2018; Hart, 2019)

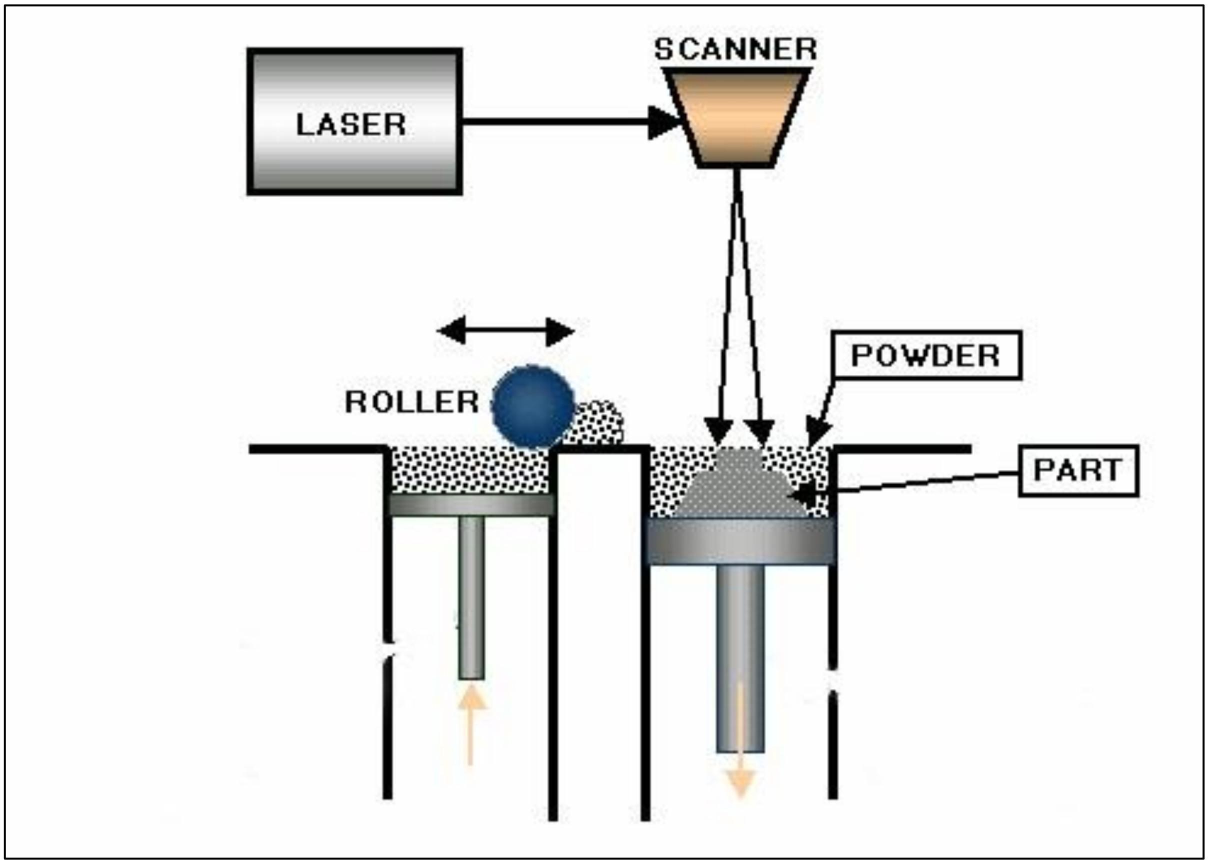

Figure 12: The printing principle of selective laser sintering based on (MKS Technologies, 2019)

The most advantageous characteristics of using SLS to print a 3D part is that there is no need for support structures, and it is the perfect solution for creating functional products having complex geometries (Oceanz, 2019).

Selective Laser Melting: SLM also lies in the main subcategory of PBF, which uses high power laser, to fully melt and fuse powders (metals) in producing final parts. Unlike SLS, SLM requires support structures due to the high temperatures involved in the metal 3DP methods. SLM functions are atmosphere control, powder spread control, and laser and optics control, which makes metal 3DP still a very expensive process. (Awand et al., 2018; Hart, 2019)

3D parts produced by PBF possess high strength, and toughness. PBF methods are often used to manufacture end products due to various post-processing methods available i.e., heat and surface treatment, support removal, machining, dyeing, painting, nickel plating etc. (Redwood, 2019; Oceanz, 2019)

During a printing process, the roughness of a surface, and contraction or alteration occurring in a part's structure, are various cons of PBF. And there are other challenges linked to PBF, such as, the handling of the powder, and the disposal of the powder during and post processing. (Redwood, 2019).

4.3.5 Direct Energy Deposition

Direct Energy Deposition (DED) is a particular type of 3DP method, which is at the frontier of material extrusion and PBF. The method takes a metal powder or a wilding wire and feeds it through a nozzle as shown in the Figure 9. A laser is used to melt the metal powder. However, the metal powder is melted at the same time as it is dropped by a nozzle. Depending on specific application, DED is subcategorized into Laser Engineered Net Shaping (LENS) and Electron Beam Additive Manufacturing (EBAM). (Awand et al., 2018; Hart, 2019)

The biggest value of DED is that there is no need of a support structure. DED is used for repairing or adding an additional material to existing parts. The method is commonly used for industrial applications such as repairing of damaged turbine blades or propellers. (Redwood, 2019)

4.3.6 Sheet Lamination

In sheet lamination method, you are laminating sheets of feedstock together. It applies one sheet at a time, and then cut the cross section of the layer to form a final part as shown in the Figure 9. In this method, layer thickness is similar to the thickness of thin sheets of material and guidelines the final quality. The layer thickness also depends on the type of machine used. (Perrot and Amziane, 2019; Hart, 2019)

Sheet lamination can be subcategorized into the following methods such as ultrasonic additive manufacturing (UAM) and laminated object manufacturing (LOM). UAM uses metals, that are bound together by ultrasonic welding, while LOM uses paper. Different materials can be bonded by using UAM. And it also needs less energy. Because in this method the metals are not melted. The advantages of sheet lamination include i.e., an easy manner of handling material, and the low cost. However, it generates a lot of waste compared to other 3DP methods. (Loughborough University, 2019)

4.4 Pros and Cons of 3DP

Recently, product manufacturing on processes level, in terms of sustainability, has gained more attention. This attention is because of the increased awareness of customers on saving the planet's resources, and protection of the environment. Most of the stakeholders such as governments, corporations, activists, and consumers are considering the sustainable nature of the products they buy. (Liu et al., 2016)

Items	**3DP**	**Conventional Manufacturing**
Forming method	Additive	Subtractive
Forms of base materials	Powders, Filaments, etc.	Blocks, Bars, etc.
Production waste	Less	More
Cost	Higher	Lower
Production time	Longer	Shorter
Required Employees	Ordinary skills required	Special skills required
Suitable applications	Making prototypes, Complex shapes	Batch production

Table 4: A comparison between 3DP and conventional manufacturing based on (Liu et al., 2016)

To further understand the new technology of 3DP, a general comparison between 3DP and conventional manufacturing has been made as shown in the Table 4. Forming methods of 3DP are additive in nature i.e., 3DP objects are developed by adding layer-upon-layer of material. In contrast, conventional manufacturing methods often require machining to remove surplus materials. Furthermore, methods of 3DP utilize powders and filaments etc., as base materials, while conventional manufacturing methods use base materials in the form of blocks and bars, etc. In comparison with conventional manufacturing methods, 3DP methods are linked with less production waste, longer production time, and higher production cost. (Liu et al., 2016)

Normally, 3DP systems are easy to operate and control. Therefore, such systems do not require a special education. On the other hand, the usage of conventional manufacturing systems require professional training, and skillful workers. (Liu et al., 2016)

Adoption of 3DP is widely due to its advantages over conventional production (Ford et al., 2016; Liu et al., 2016). 3DP is common in industries like aerospace, automotive, artistic, architectural and medical. Many low volume services parts made of titanium is used for aerospace applications. If such titanium parts are manufactured using 3DP technology, it reduces the production related costs by 30-35% (D'Aveni, 2015). There are several other advantages, which 3DP offers i.e., simplifying supply chain, reduction in lead times, more liberty in designing, and betterment in the quality of prototyping, etc. (Neghi and Sharma, 2013). An increase in computational power and software's quality has further reduced the cost of 3DP, and has detected high amount of savings in terms of time (Neghi and Sharma, 2013).

High volumes of waste materials are generally generated by subtractive manufacturing technologies (such as CNC milling), while 3DP, only uses the material needed to build a part. The raw materials used by different types of 3DP methods can also be recycled, and re-used in more than one builds (Redwood, 2019). When 3DP is adapted for metal products, wastes in terms of material are decreased by 40%. (Neghi and Sharma, 2013)

Furthermore, 3DP has already exposed and revealed its high potential in the medical sector (Neghi and Sharma, 2013). Now a days, in the field of tissue engineering, the researchers are trying to include 3DP, for the purpose of creating new and innovative biochemical parts (Neghi and Sharma, 2013). 3DP implants have a huge capacity to save and improve human lives (World Economic Forum, 2020).

However, 3DP also encounters various challenges, which limit its usage in various applications. For example, 3DP is not applicable to produce high strength parts, because of the nonlinear behavior of a part, produced by 3DP. This nonlinear behavior is due to the fact, that parts produced by 3DP, experience different strength in multiple directions. This is true, if compared with parts, that are manufactured conventionally. In lateral direction, as related to build up direction, they display high strength. Also, the stair-stepping phenomenon is considered as a problem, which is only common in 3DP systems that are projection based. This means, that parts roughness, and their surface quality will be disturbed, if in cross section, there are rectangular slicing layers. This is because, they will not be able to reunite with the curved surfaces, so as a result the roughness, surface roughness problem will remain. In terms of personal use, some low-cost 3DP systems are available in the market. These low-cost 3DP systems have been sold in large numbers, and has high demand, but enough challenges of high potential still exist. (Neghi and Sharma, 2013; Ford, et al., 2016)

3DP systems manufacture products in a democratized and customized manner. 3DP is rolling swiftly with the passage of time. It is transforming the "Design to Manufacturing" process. 3DP is also changing the future of product development, and production. Therefore, the need of new and creative BM is likely to arise, which is a challenge for many companies to cope with. (World Economic Forum, 2020)

Current research on 3DP and its impact on BM is scarcely available i.e., there is a research gap in addressing the change issues related to 3DP on BM level i.e., value proposition, financial risks (because of high investments), customer relations, key partners, and new competences. Therefore, a general view, including all parts of a BM in relation to 3DP, will be an important to topic for a research. (Öberg et al., 2018)

CASE STUDY (PART 3)

The process of transforming from a conventional BM towards a new SMB is not an easy task for many companies as this transformation faces several challenges as described in subchapter 3.3, and companies will face some of them as they adopt a new SMB (Geissdoerfer et al., 2018). And especially, this process of transformation becomes very challenging for the 3DP manufacturers since the current research does not addresses the change issues related to 3DP on BM level as described in subchapter 4.3. To comprehend these challenges (Geissdoerfer et al., 2018; Öberg et al., 2018) in more detail, this case study was conducted in corporation with HAGE3D on a top management level.

5. The Company HAGE3D

HAGE3D is an independent family-owned Austrian 3DP systems manufacturing company, initially founded from HAGE Sondermaschinenbau (HAGE, 2019). The story of HAGE Sondermaschinenbau dates to the year 1982, where it was founded by Mr. Gerfried Hampel in Obdach, Styria. The company works exclusively in contract manufacturing, and producing custom high-tech systems completely independently for the entire world. Both companies, i.e. HAGE 3D and HAGE Sondermaschinenbau by now are connected under a parent company, i.e. HAGE Holding (HAGE holding, 2019). The role of commercial and technical leadership of the parent company is headed by second generation of Hampel's family members.

For several years HAGE3D has been researching and developing reliable 3D printers. They are experts in the field of 3DP, mechanical engineering, electrical engineering, plastics engineering, and mechanics. HAGE3D operates at two locations, and conduct different business activities. The first location of HAGE3D is, the Technology Park (called SPACE ONE), which is operational in the city of Graz since 2018. The prime goal of the company here is to advance the full potential of material extrusion methodology (ISO/ASTM, 2015). Research and development operations take place in terms of process and material development. The team at Graz is multidisciplinary, containing material scientist, machine developing technicians, and business leaders. The important advantage of this technology center for HAGE3D is to sustain a strong and close network with other stakeholders in the region related to 3DP industry. This gives the company new opportunities to work on new developments and explore new markets for their products. The second location is in Obdach, Styria, where the company has been producing 3D printers for international customers, and other partners since 2014. (HAGE3D, 2019)

The company's 3D printers offer solutions using material extrusion technology (ISO/ASTM, 2015). The specific printers promise detail accuracy and highest precision. To further get a better overview about the company's product portfolio, the five different kinds of 3D printers, offered by HAGE3D to its customers till date are discussed below. (HAGE3D, 2019)

HAGE3D 3D PRINTER 72L

The Model 72L as shown in Figure 13 provides a convenient solution for engineering plastics. The processes performed by the printer is for highly dynamic FFF rapid prototyping. And aptitudes an accuracy of in-depth and high consistent accuracy up to 0.1 mm. (HAGE3D, 2019)

Figure 13: HAGE3D 3D PRINTER 72L (HAGE3D, 2019)

HAGE3D 3D PRINTER 84L

This type of printer shown in Figure 14 functions in the same way as HAGE3D 3D PRINTER 72L. For all available filaments, it contains a new dual printhead. These filaments may be engineering plastics, metal filaments, or others. This printer model is good for the enamel coating process. (HAGE3D, 2019; Nolifrit, 2019)

Figure 14: HAGE3D 3D PRINTER 84L (HAGE3D, 2019)

HAGE3D 3D PRINTER 140L

HAGE3D 3D printer 140L is shown in Figure 15. It has a space of installation for parts up to 700 x 500 x 400 mm. The printer optimizes a handler's comfort, and maintains an industrial control, and further provides high-performance plastics in terms of shape from 300° C up to 450° C of temperature. (HAGE3D, 2019)

Figure 15: HAGE3D 3D PRINTER 140L (HAGE3D, 2019)

HAGE3D 3D PRINTER 175C

This model is shown in Figure 16, which operates on High Friction Feeding System (HFFS) technology. The printer contains a large heat-able built chamber (of size up to 1.200 x 1.200 x 1.200 mm), which can be heated up to 80 ° C of temperature. Additionally, the printer has an LED interior lighting, and the ability to use different variety of materials. (HAGE3D, 2019)

Figure 16: HAGE3D 3D PRINTER 175L C (HAGE3D, 2019)

HAGE3D 3D PRINTER 175X

The HAGE3D 3D printer 175X shown in Figure17, has 5 axis operational capabilities, which enables the printing of complex parts without the usage of any supporting material. The highest precision of mechanical engineering can be easily witnessed in the special HAGE GANTRY 5 axis model 175X printer, which is generally armed with a servo motor, an absolute encoder, and certain ball screws in XYZ directions, where the maximum level of consistency is guaranteed. HFFS developed by the firm for printhead is mounted on a 3-axis cartesian carriage unit (X / Y / Z), and the printing object is built on a 2-level rotatable print table. (HAGE3D, 2019)

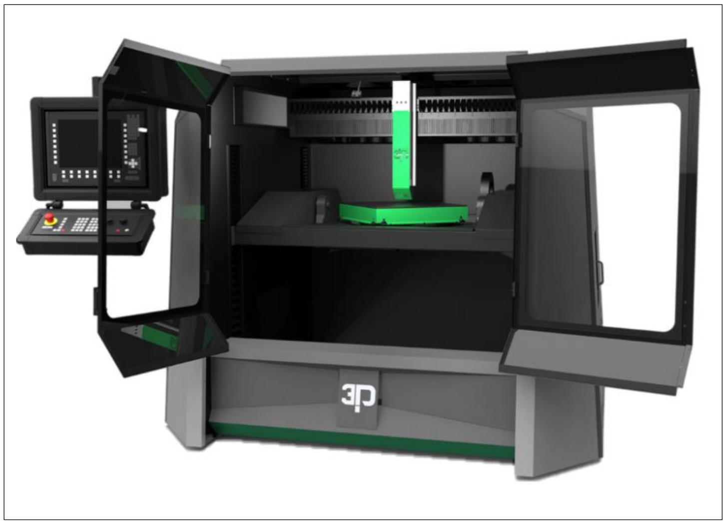

Figure 17: HAGE3D 3D PRINTER 175L X (HAGE3D, 2019)

Without any support structures, HAGE 3D printer 175x provides a unique possibility for the construction of complex parts. The core customers of the company by now are original equipment manufacturers (OEMs), and Tier 1 suppliers from automotive industry, aerospace industry, electronic goods industry, and chemical industry. There are mechanical engineering SME, companies which are also HAGE3D’s customer. Other companies related to research and development from other sectors also fills the list. (HAGE3D, 2019)

HAGE3D is doing business in various markets and industries using a conventional BM, which means, that the environmental and social aspects of the business aren’t fully considered on a BM level (Joyce& Paquin, 2016). Recently, the company’s management has desired to target the medical market with their new 3DP system, which has further created the need of a new BM for the medical market. This strategic move is made due to the fact of a high global demand for 3DP medical implants (WEF, 2020). The medical market is a total new market for HAGE3D. There will be challenges as well as opportunities for the company linked to their new 3DP system for medical market (Öberg et al., 2018). These challenges and opportunities are in terms of new design, new materials, new stakeholders, supply chain, etc. (Öberg et al., 2018). Therefore, at the same time, HAGE3D also wants to create a new SBM for the medical market.

6. Research Design

There are two main types of a research i.e., a qualitative research and a quantitative research, and both have different research approaches. Qualitative research does not produce findings by statistical procedures, or by other means of quantification. On the other hand, during quantitative research, the data collection process is done by quantification, and data is analyzed through mathematical and statistical process of interpretation. (Yin, 2009; Ghezzi, 2020)

The extension and generalization of scientific theories with some new empirical insights connecting it with the existing literature is achieved through case study research (Yin, 2009). And sometimes it becomes very important for a topic on which there isn't any availability of extensively scientific work (Vissak, 2010).

Case study, as a research method, falls into the set of qualitative methodologies, which differs from other qualitative research methods such as, qualitative surveys, or collaborative research methods. Various steps in defining a methodology of a case study are i.e., deciding the unit (s) of analysis, selecting cases, collecting data, analyzing data, and interpreting the findings. A unit of analysis identifies where the phenomenon investigated is located, and what will be the main object under critical observation and examination. Individuals, organizations, processes, social programs, decisions etc., can be considered as unit of analysis during a case study research. In order to enable comparability of results with previous studies, the research should try to select a unit of analysis that is or can be used also by others. In designing a case study's unit of analysis, the first decision to make, concerns with the selection of a single case study or a multiple case study. And also, concerns with the holistic or embedded nature of the unit of analysis. All four kinds of case study designs are shown in figure 18. (Yin, 2009; Ghezzi, 2020)

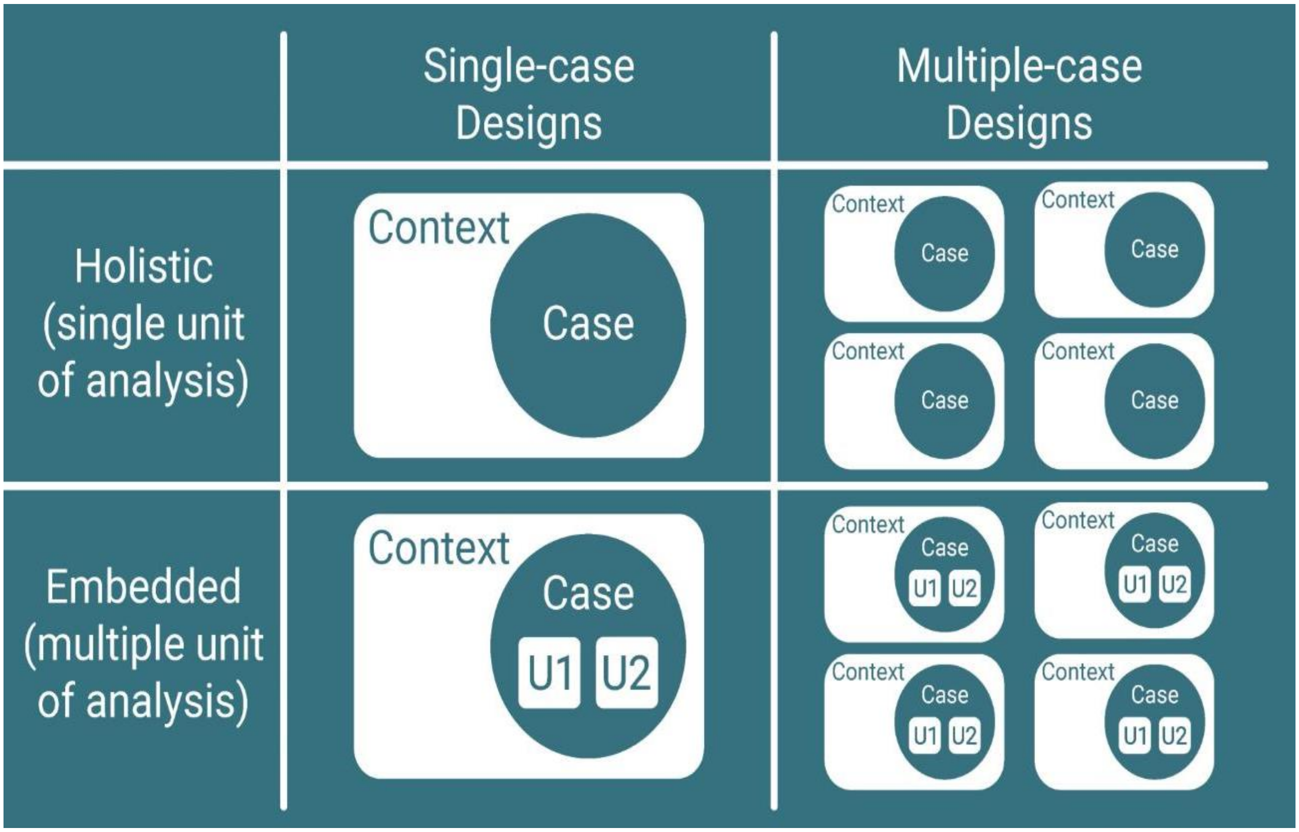

Figure 18: Basic types of designs for a case study based on (Ghezzi, 2020)

1. **Single-case holistic design:** A single case study based on holistic approach, which considers a single unit of analysis for single context analyzed. (Yin, 2009; Ghezzi, 2020)
2. **Single-case embedded design:** The requirements for such case design is a single case with an embedded approach, that focuses on multiple unit of analysis for single context. (Yin, 2009; Ghezzi, 2020)
3. **Multiple-case holistic design:** This kind of design talks about the study to be conducted on multiple cases. Here, a holistic approach considers a single unit of analysis for each context analyzed. (Yin, 2009; Ghezzi, 2020)
4. **Multiple-case embedded design:** Such case design states to be conducted if there are more than one case. And, multiple unit of analysis are performed on multiple cases. focuses. (Yin, 2009; Ghezzi, 2020)

Case study gathers data, mainly based on human words, behavioral observations, and archival documents. And analysis of the gathered data is done by non-mathematical and non-statistical methods. (Yin, 2009; Ghezzi, 2020)

The case study research methodology is criticized by not providing enough robustness as a research tool, but still suits well by investigating events from real time scenarios for answering research questions, that include how, and why. (Yin, 2009)

The aim of this master thesis is to generate new data (or research) on the process of a company's transformation from a conventional BM to a SBM in practice, for a 3DP system manufacturer. The research design selected, and applied, is the qualitative single case holistic design. The study carried out is based on information which is publicly available and qualitative data, obtained through an interview and a workshop conducted on an executive management level (Yin, 2009). A paradigmatic case of creating a specific SBM type was chosen, which integrates the products and services of a 3D printer manufacturing (Geissdoerfer et al., 2018). The qualitative single case study under consideration is unique when one thinks about a 3DP system manufacturer, and the process of developing a SBM for the medical industry.

6.1 Interview

One of the ways to gather data in a case study is by means of interviews. And such qualitative data initially can be obtained by conducting different kinds of interviews, such as, standardized, unstandardized, or semi-structured interview. A standardized interview is designed to collect data using a set of predetermined questions about the case study, while in an unstandardized interview the only question an interviewer asks from an interviewee, or interviewees, is about the main research topic, or question. And later develops, adapts, and generates new questions during an interview. On the other hand, a semi-structured interview is a mix of both, where an implementation of several predetermined questions is used as an unorganized starting point to drive the discussion. Whereas, an interviewer is also allowed to examine the main research topic beyond prepared questions. (Yin, 2009; Ghezzi, 2020)

For this case study, a semi structured interview based on Bryman and Bell (2011), was designed and conducted in terms of flexibility, order, and overall design to generate initial qualitative data. The goal of the interview was to know and document the perspective of HAGE3D's management (responsible for the creation of a new BM for the medical sector) on the topic of this thesis, and about the company's vision, business, and history.

Q. Overview about the company HAGE i.e. history, vision, mission, business units and guiding principles?

Q. Why did the creation of HAGE3D occurred at first place?

Q. What were the external and internal factors responsible for this move?

Q. Who are your shareholder?

Q. When did you started working? What has been your journey so far?

Q. With HAGE3D, how the company new identity is reframed?

Q. How much time your first product took as a functional 3D printer?

Q. With HAGE3D product line targeting a new Industry (Medical) so how this decision was taken? Or still it's in consideration of which this case study is a part?

Q. Do you have any BM for HAGE3D, and is it the same as HAGE?

Q. Have you developed any of your own innovation matric for BM innovation during the last decades?

Q. When one triggers the term sustainability, what comes first into your mind? Or what does sustainability mean to you?

Q. As a company, do you feel pressure to be sustainable from any dimension?

Q. Moving from a conventional BM business model to a more SBM will require a sustainability strategy? Or this was never included in the company's overall strategy?

Q. What are the most important factors for you to consider, during the process of moving from a conventional BM to SBM?

- Sustainable value
- Proactive multi-stakeholder management
- Long term Perspective

Q. Have you reviewed the market segmentation of medical industry (locally and globally), and demographically which market will be on your priority?

Q. Have you done any rough value networking of your stakeholders?

Q. When we talk about market competitiveness, which drivers are important to you i.e. innovation or price or sustainability in terms of medical industry?

Q. Are you offering just a product or something more, i.e. a kind of product service system (e.g. digital app etc.)?

Q. What is HAGE3D market share in medical 3DP industry?

Q. Stakeholder perspective can be network centric or firm centric. What is important for you?

Q. Talking about design thinking process (i.e., to understand, observe, define, ideate, prototype, and test), do you consider sustainability in such process?

Q. What could be the biggest opportunities for the leadership of HAGE3D leadership within the medical market? Q. What are the risks and challenges (internal and external) for HAGE3D to attain the initial goals, regarding its 3DP system for the medical sector? Q. Would you like to add anything extra? Have we missed anything, that you would like to add?

Table 5: A semi-structured interview questionnaire based on Bryman and Bell (2011)

The interview was conducted face-to-face with the following interviewees:

- Head of R&D from HAGE3D as interviewee 1.
- CEO from HAGE3D as interviewee 2.

Furthermore, the interview questionnaire, as shown in Table 5, was prepared according to the background of the company, the main topic of the thesis, and subtopics related to the main topic. Both the interviewees were asked the same questions. The data generated during an interview, was collected simultaneously in the form of handwritten notes, and an audio recording at the main office of HAGE3D, located at Graz. Such content represented the primary sources of evidence for the case study.

6.2 Tools Used

There are various challenges described by Geissdoerfer (2018), which are linked to the creation of a SBM. The selection of tools, in the process of sustainable business modelling, is one of various challenges as explained in subchapter 3.3. This is true, because most of the exiting business modelling tools are rarely sustainability driven (Geissdoerfer et al., 2018).

During this case study, few tools as discussed in subchapter 3.4 were used to practically translate the theoretical research of a SBM. Figure 19 provides the summary of the toolchain, and the purpose of each tool in terms of its usage.

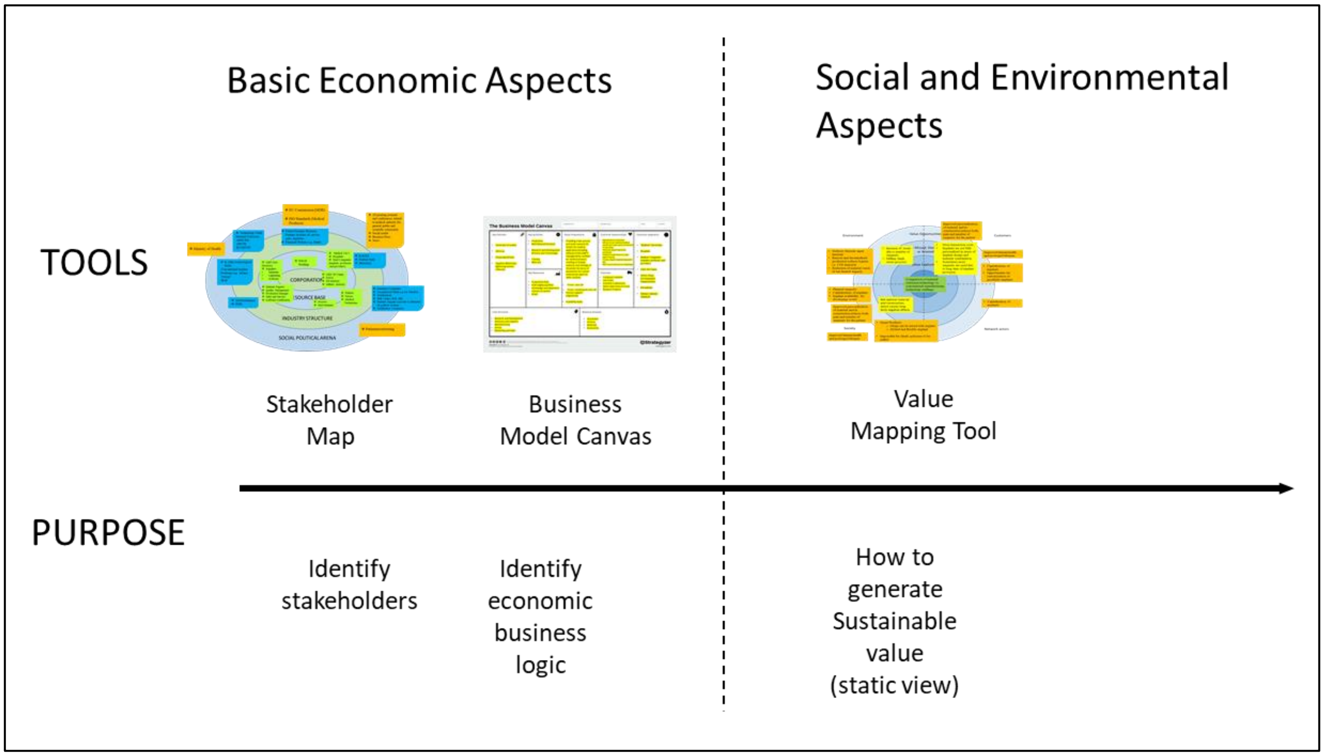

Figure 19: An Overview of applied tools and their purpose based on (Shah et al., 2020)

As explained in chapter 3, it is important for a SBM to incorporate the management of proactive multi-stakeholders (Geissdoerfer et al., 2018). Therefore, at first, a deep review of all stakeholders on various levels for HAGE3D was important. For this purpose, a stakeholder map by (Fassin, 2009) was used as starting point during the process of creating a new SBM. The goal was to depict all stakeholders, which are linked to the 3DP system of HAGE3D for medical sector.

Afterwards, a BMC (Osterwalder & Pigneur, 2010) was used, that was already filled with data. This data was based on an earlier interview, conducted together with executives of HAGE3D, as explained in subchapter 6.1. The data of a BMC (Osterwalder & Pigneur, 2010) was further discussed and refined, after the usage of a stakeholder map (Fassin, 2009), during the workshop. The purpose was to get an idea on the business for one more time in a collective manner, before the usage of another tool.

A SBM creates a sustainable value as explained in chapter 3. A value, that integrates economic, social, and environmental aspects of a business, system, or product (Geissdoerfer et al, 2018). For the purpose of creating a non-monetary value (i.e., social and environmental) for the 3DP system of HAGE3D, a VMT (Bocken et al., 2013) was used. Later, data generated during the workshop, by using a stakeholder map (Fassin, 2009) and a VMT (Bocken et al., 2013), was digitalized. And at the end, once again a BMC by (Osterwalder & Pigneur, 2010) was used to summarize all gained data in a digitalized manner.

The overall goal of using all these tools were to create a new SBM, which can help HAGE3D to differentiate themselves from other competitors on a medical market. These tools as practical resources were helpful in the process of creating a new SBM for HAGE3D.

6.3 Workshop Setup

The outcomes of this workshop are based on data gathered during desk research and a preliminary interview conducted together with executives of HAGE3D. To advance and gather further details on the thesis topic, a workshop was conducted with the following stakeholders:

- CEO from HAGE3D.
- Head of R&D from HAGE3D.
- Researchers from the Institute of Engineering and Business Informatics, TU Graz.

The setup was designed to highlight all the stakeholders of HAGE3D, and to discover a sustainable value for the company and their business activities in long term. All practical activities related to the workshop took place in a seminar room at the Graz University of Technology. Following topics were addressed during this workshop:

- Status presentation of the project
- Presentation and usage of a stakeholder map
- Presentation and usage of a VMT
- Closing remarks and discussion

In the beginning of a workshop, a small review about the semi-structured interview and SBMA (Bocken et al., 2013, Short et al., 2012) were presented. Afterwards, a roughly filled new BMC (Alexander & Osterwalder, 2010) was presented. This BMC was based on data from earlier desk research, and semi-structured interview. During the presentation, extra data was collected and corrected on the basis of feedback from HAGE3D.

The workshop was facilitated using several tools i.e., a stakeholder map (Fassin, 2009), and VMT (Bocken et al., 2013). Before the workshop, a stakeholder map and VMT were printed in a large format for the purpose of its usage during the workshop. Both tools were explained to the participants of HAGE3D in terms of its functionality and usage.

At first a stakeholder map was used. The aim of this step was to facilitate the identification of all stakeholders of HAGE3D in a simple, and organized manner. Therefore, all stakeholders were identified as a result of input from HAGE3D by using a stakeholder map (Fassin, 2009).

Afterwards, a VMT was presented. To support the workshop facilitators, a VMT guideline published by (Rana, 2010) was adopted. The tool was used and filled by all participants by comparing material extrusion technology (ISO/ASTM, 2015) with other conventional manufacturing technologies. The purpose of this step was to facilitate the executives of HAGE3D in the process of recognizing and creating a sustainable value for their 3DP system (Geissdoerfer et al., 2018).

In the end, all participants once again discussed reviewed data, which was generated by using a stakeholder map (Fassin, 2009), and VMT (Bocken et al., 2013). The purpose of this revision was to refine data with some minor inclusions, exclusions. After the workshop, data from stakeholder map and VMT were digitalized. And as a result, a new SBM was created using a BMC (Osterwalder & Pigneur, 2010), which is described in chapter 7 in more detail.

7. Results

This chapter represents, an overview of the process of developing a SBM using various tools for a 3DP system manufacturer.

7.1 Interview (Results):

The interview was a great help to create an initial and deep understanding about HAGE3D. It helped to provide the basic idea about the company's history, size, nature, vision, business units, product portfolio, and culture. Initially, the questions asked were related to sustainability and SBM, which were helpful in creating a clarity on the topic among the participants through communication, and important challenges linked with the topic were discussed in an exploratory manner. The following results were generated from the interview:

- The driving factors of BM change for HAGE3D were both, external and internal. The external factor was due to the fact that the market for 3DP implants is expected to grow significantly in the coming years due to the technological advancement in 3DP. To further expand the business, and to stay ahead in the game by targeting the medical market, the executives of HAGE3D realized internally, the necessity to create a new BM (WEF, 2020).
- Both the interviewees barely feel any pressure concerning sustainability. This suggests that during the process of product development and the process of BM creation, the management of the company feel less internal or external pressure to integrate the concept of sustainability (Geissdoerfer et al., 2018).
- The SDG are not on company's top priority, however the interviewees discussed it in detail on a personal level. This indicates that SDG are not the first priority of many businesses (Sachs, 2015).
- Going from conventional BM to SBM one needs a sustainable strategy. Till now, HAGE3D didn't have created a sustainable strategy (Rainey, 2006).
- Table 6 shows the response of both the interviewees, when were asked about the pressure during work, that they feel regarding the three main pillars of sustainability. Both the interviewees feel an economic and a social pressure, and barely conceive an environmental pressure. This suggests, that the co-creation of social and environmental benefits beside profits is not simple rather challenging (Geissdoerfer et al., 2018).

	Economy	Society	Environment
Interviewee 1	Yes	Yes	No
Interviewee 2	Yes	Yes	No

Table 6: A response of the interviewees based on the three pillars of sustainability based on (Olson, 1996)

- The interviewees were asked to prioritize the following three factors of SBM (Geissdoerfer et al., 2018) as shown in Table 7. The proactive multi-stakeholder management was on top priority for both the interviewees, while opinions of both differed on the other two factors. The Interviewee 1 placed sustainable value, second in priority, while long term perspective was placed at last. On the other hand, the interviewee 2 mentioned the opposite. This result shows that business and R&D executives have different priorities regarding, the factors of SBM. However, both have common and top priority for all the stakeholders. A sustainable value here means the integration of economic, social, and environmental values (Geissdoerfer et al., 2018).

Interviewee 1 (Priority)	Interviewee 2 (Priority)
Proactive multi stakeholder management	Proactive multi stakeholder management
Sustainable value	Long term perspective
Long term perspective	Sustainable value

Table 7: A response of the interviewees regarding the three factors of SBM based on (Geissdoerfer et al., 2018)

- Sustainability was not conceived as a competitive driver for the 3DP medical products by both the interviewees. For the interviewee 1, innovation was a competitive advantage while the interviewee 2 prioritized price over innovation as shown in Table 8.

Interviewee 1 (Priority)	Interviewee 2 (Priority)
Innovation	Price
Price	Innovation
Sustainability (not at all)	Sustainability (not at all)

Table 8: A response of the interviewees regarding the competitive drivers for the medical 3DP products based on (Geissdoerfer et al., 2018)

- A deep understanding about the stakeholders, which have the potential to disrupt the business in terms of laws and regulations was discussed. The list of such stakeholders in terms of a medical industry includes doctors, politicians, and various institutions. 3DP is getting more involved in many medical activities, therefore, law can't be apart from it. One of the big challenges (associated from the legal system point of view) for the leaders (associated to 3D printed implants business) is to foresee the regulations related to the new technology, and the product in terms of 3DP medical systems. During the interview, the future regulations (associated to 3D printed implants) were considered as the biggest risk because it is directly related to the financial risk. Both the interviewees talked about the technological and financial risks, that they see from inside, and outside of the company. They also mentioned the legal and regulatory risks attached to the business of 3DP in the medical industry. This result shows the importance and influence of stakeholders, and suggests to maintain a strong connection with them (Geissdoerfer et al., 2018).
- HAGE3D is interested in the European medical market with a special priority on the German speaking countries.

7.2 Stakeholder Map (Results):

Since the factor of pro-active multi-stakeholder management for SBM is on top priority for the management of HAGE3D (Geissdoerfer et al., 2018), therefore it was required to study all the stakeholders of the company. To represent all the stakeholders of HAGE3D was a challenge, which was impossible to overcome during a semi- structured interview. Therefore, a stakeholder map (Fassin, 2009) was used to identify all the stakeholders of HAGE3D during the workshop as mentioned in subchapter 6.3. Figure 20 represents all identified stakeholders on a stakeholder map in a digitalized form.

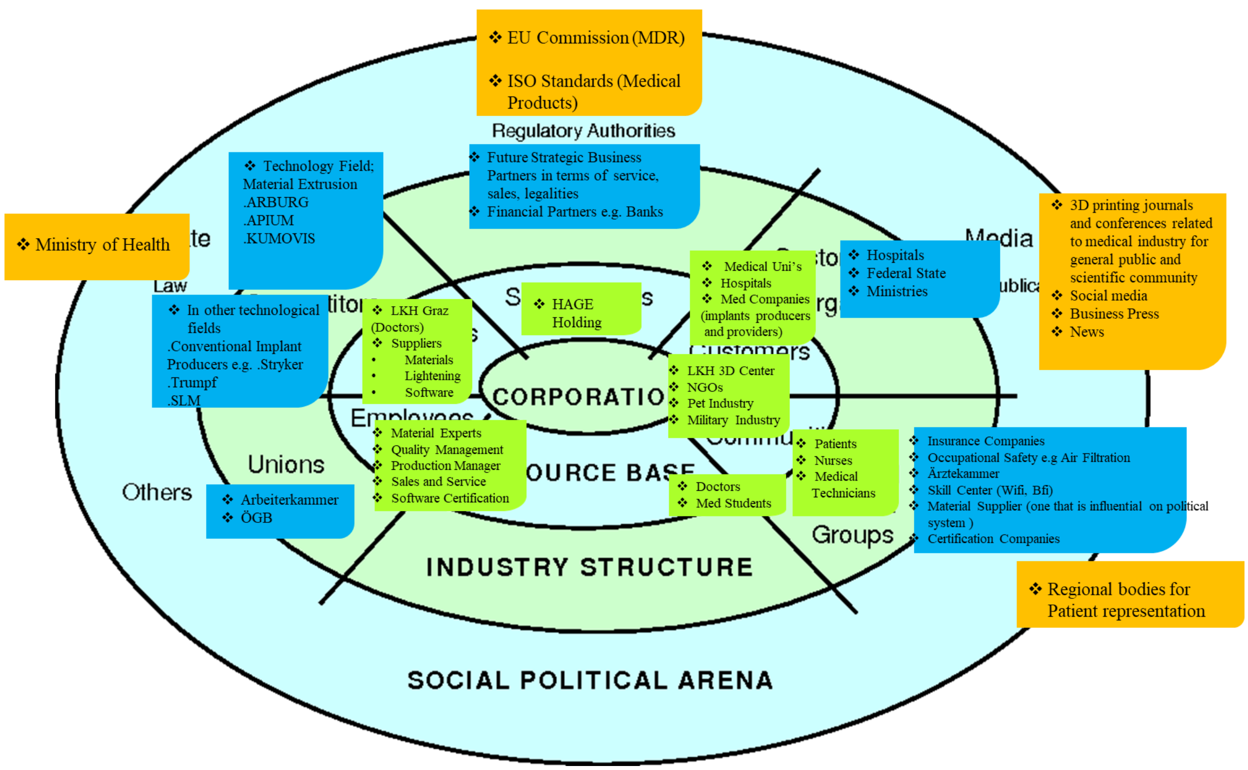

Figure 20 : A Stakeholder map based on (Fassin, 2009) populated with data obtained from a workshop with HAGE3D

The list of stakeholders having an influence on the medical business of HAGE3D are categorized according to the three layers of a stakeholder map (Fassin, 2009), which includes a resource base, an industry structure, and a social political arena.

The stakeholders in a resource base are of the highest importance, which are further divided into the following five groups:

Employees: The company employees i.e., material experts, quality management professionals, production managers, sales and service providers, and software certification specialists are the essential stakeholders for HAGE3D.

Customers: All medical universities and hospitals are considered as potential customers by HAGE3D. The Medical companies, which produce and provide medical implants are customers to the company's 3DP system, and also the 3DP center located at the city hospital of Graz. In future, the company expects many potential customers from the pet industry, and the military industry. HAGE3D has a clear sales policy, that they will sell their 3DP system to military customers only for rescue purposes, and the same for non-government organizations (NGOs) working with, or working in the developing countries for humanitarian missions. This policy translates the mindset of HAGE3D leadership, and serves as a foundation, for creating a strong moral and social value for their products, and future customers in the medical market.

Business partners: The company considers all the medical doctors as business partners. Furthermore, the core suppliers that provide lighting systems and materials, and develop software for HAGE3D also fills the list of business partners.

Shareholders: HAGE holding, which is the parent company is the only shareholder of HAGE3D.

Communities: Many actors in the medical industry like medical doctors, medical students, patients, nurses, and medical technicians are positioned in this group.

Now the stakeholders of HAGE3D residing in the layer of industry structure (of stakeholder) map are categorized in five groups are shown in Figure 20, and are discussed below:

Competitors: HAGE3D considers those companies as direct competitors, which are selling 3DP systems based on the material extrusion technology (ISO/ASTM, 2015). Whereas, in future, it also considers the conventional medical implants producing companies, as a potential threat for the market share competition.

Investors funds: Future strategic business partners in terms of services, sales, and legalities are considered here. In the future, banks as financial partners may also be considered. This data indicates, that in a 3DP business the connection between a 3D printer manufacturer, and its key business partners creates a value from various perspectives, which brings nearly a practical confirmation to the research work of Öberg et al. (2018). At first, the strategic business partners by HAGE3D are considered as service providers and legal advisors, but later also as investors.

Customer organizations: Hospitals and other Austrian federal state ministries are also considered as stakeholders here.

Special interest groups: Insurance companies, national skill centers, national and regional union of doctors, groups responsible for occupational safety (i.e., air filtration), and companies performing various kind of certifications are listed in the special interest groups. The company also considers the material supplier, which has a strong influence on political system in terms of doing legal lobbying for their products.

In social political arena, the following stakeholders were identified, and classified accordingly into the five different groups:

Government regulatory authorities: The EU commission for medical devices regulation (EU, 2019), and the ISO standards for medical products (ISO, 2016) are stakeholders considering government regulatory authorities.

Media publications: This includes all the 3DP journals and conferences related to the medical industry for general public, and scientific community. News, social media, and business press are also considered in this section of social-political arena.

Civil society: Regional bodies for patient representations highlighted in the group of civil society as stakeholders.

State law: Ministry of health (Austria) is placed as a stakeholder in the category of a state law.

It was hard to find stakeholders for the section, others. Therefore, it was left empty. All the stakeholders were simply and easily identified during the workshop with the help of a stakeholder map (Fassin, 2009).

7.3 Value Mapping Tool (Results):

The second tool used during the workshop was a VMT (Bocken et al., 2013). Figure 21 illustrates the results by comparing, the material extrusion technology (ISO/ASTM, 2015) with other conventional manufacturing technologies for HAGE3D in terms of a value missed, and the value opportunities on four different dimensions for medical implants.

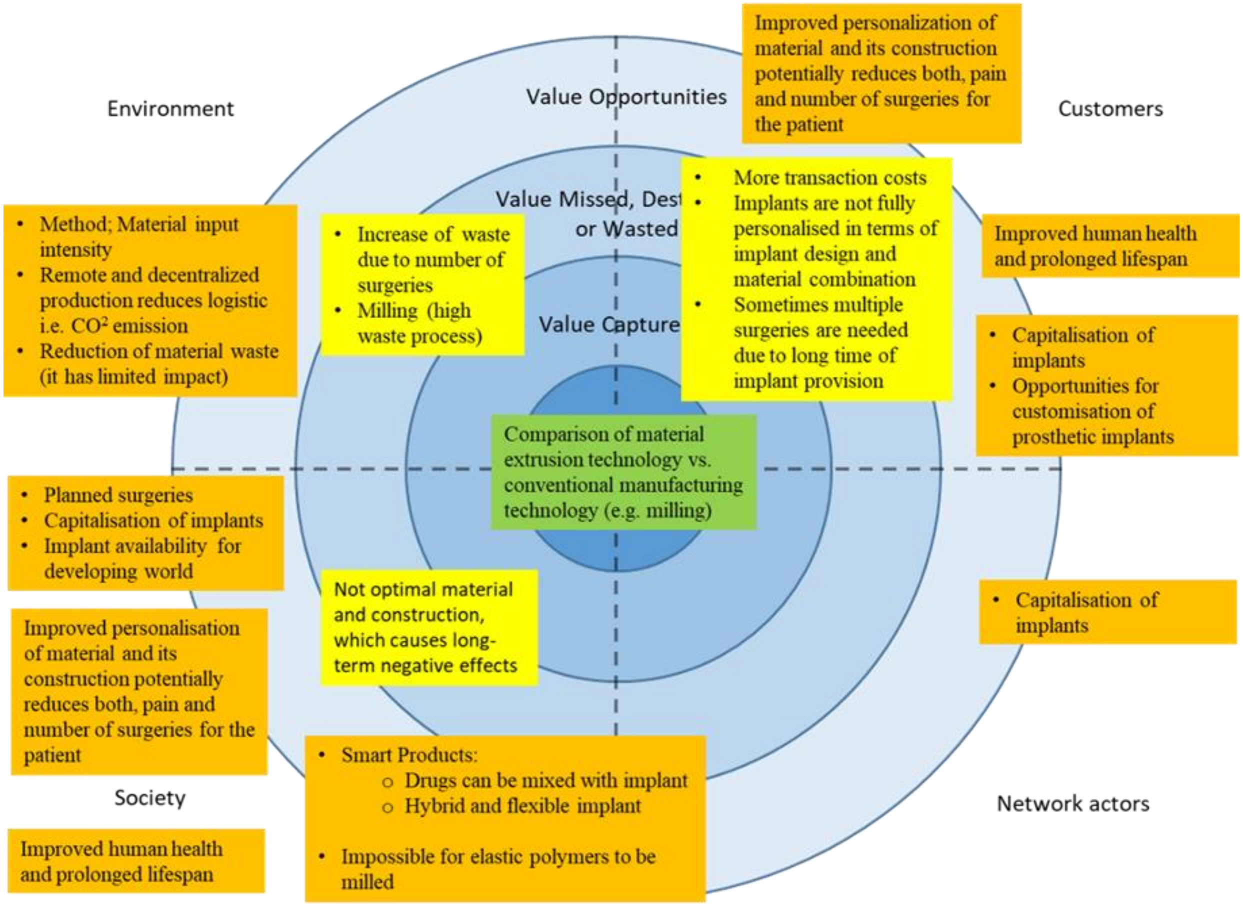

Figure 21 : A Value mapping tool (Bocken et al., 2013) populated with data obtained from a workshop with HAGE3D based on (Shah et al., 2020)

The value missed on the following four dimensions are:

Customers: There were more transactional costs for customers due to the conventional manufacturing technologies. For the end users, implants were not fully personalized in terms of designing, and material combination. Multiple surgeries were done by the patients, because the provision of implants wasn’t possible in a short time. (Shah et al., 2020)

Environment: More material waste was connected during the development of implants through the conventional manufacturing technologies. (Shah et al., 2020)

Society: The conventional way of developing an implant has long term negative impacts on the society due to the non-optimal material, and the method of its construction. (Shah et al., 2020)

Network actors: The participants did not figure out any value missed on this dimension. (Shah et al., 2020)

The value opportunities realized on the following four dimensions are:

Customers: Increased personalization, and an improved construction methodology of implants, possible due to the material extrusion technology created many benefits for customers i.e. reduction in pain, improved human health, prolonged lifespan, and lower number of surgeries per patient. The capitalization of implants is another benefit, which means the reduction of cost due to an easy, quick and decentralized production. The customization of prosthetic implants also adds an extra value for the end-customers. (Shah et al., 2020)

Environment: Decentralized production possible due to the material extrusion technology reduces logistics, which reduces carbon dioxide emissions. And waste is also small due to low number of surgeries. In order to calculate the carbon dioxide emissions, one can use material input intensity method. (Ritthof et al., 2002; Shah et al., 2020)

Society: The biggest value opportunity for a society is the smart implants, which means the opportunity to mix drugs during the production of implants. This makes the implants more hybrid and flexible, and surgeries become more planned. Benefits such as reduction in pain, low number of surgeries, improved human health, prolonged lifespan, and capitalization of implants were also positioned on this dimension. Elastic polymers can be used by the material extraction technology which was impossible to be milled with conventional milling technology. (Shah et al., 2020)

Network actors: The participants positioned only one value opportunity on this dimension i.e., the capitalization of an implant. (Shah et al., 2020)

7.4 Business Model Canvas (Results):

The data gathered from the practical use of SBM tools i.e., a stakeholder map (Fassin, 2009), and a VMT (Bocken et al., 2013) during the workshop, was finally utilized to create of a SBM for HAGE3D using the BMC (Osterwalder & Pigneur, 2010), which is a contribution to the earlier research work of Öberg et al. (2018) and Geissdoerfer et al. (2018). Figure 22 illustrates the nine components of a BMC (Osterwalder & Pigneur, 2010), which provides an organized and detailed explanation on the key aspects of how HAGE3D creates profit, and delivers sustainable value to its customers in the medical market. (Shah et al., 2020)

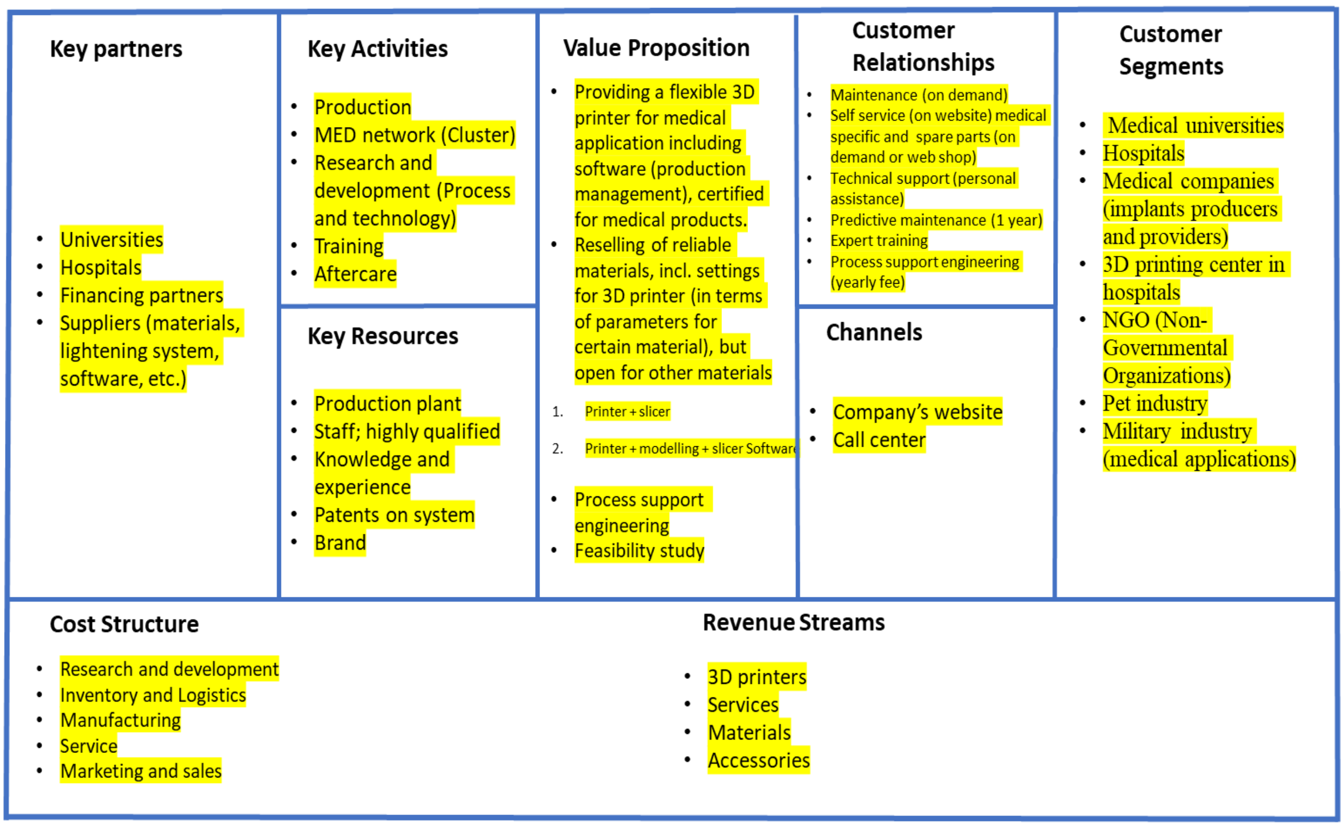

Figure 22 : BMC (Osterwalder & Pigneur, 2010) demonstrates HAGE3D case based on (Shah et al., 2020)

Value proposition: HAGE3D creates a value by offering a flexible and certified 3DP system for medical application including software for production management. This software is certified for the medical products, as well for the reselling of the reliable material. And the software also includes the settings option for a 3D printer (i.e. parameters are set for certain materials, but can also be adapted for other materials). (Shah et al., 2020)

The following 3DP system packages are being offered in the medical sector by HAGE3D:

- Printer + slicer software
- Printer + modelling + slicer software

Other things like, process support engineering and feasibility study are also counted as value propositions. (Shah et al., 2020)

Key partners: The key partners for HAGE3D are universities, hospitals, financial partners (e.g. banks), and numerous core suppliers in terms of materials, software, and lighting systems. (Shah et al., 2020)

Key activities: The medical cluster of various business stakeholders is important to the company in terms of networking, collaborating, and following new trends. The research and development team focuses on the process and technological advancements related to the system. Trainings on the new advancements are also given to their staff members and clients. After the 3DP systems are sold, the company offers a customer care service. (Shah et al., 2020)

Key resources: The company's brand and patents are vital key resources. Employees' knowledge, skills, and experience are intangible assets for HAGE3D. Lastly, the production plant that manufactures the 3DP products is also a crucial company resource. (Shah et al., 2020)

Customer segments: Generally, all medical universities, hospitals, and medical implant producers and providers (using conventional manufacturing methods) are potential customers of HAGE3D, whereas the 3DP centre in the hospital of Graz also use HAGE3D systems for study purposes. The pet industry is also considered in this segment because in future the demand will increase for customized 3DP products for pets. NGOs, and any military partners involved in humanitarian missions in remote areas of the world are also considered as potential customers. (Shah et al., 2020)

Customer relationships: HAGE3D offers the technical-support process engineering with a yearly fee, on-demand maintenance, personal assistance, free predictive maintenance for up to one year, and an online or direct availability of medical specific products and spare parts, which creates a strong relationship with their customers. Meetings with the members of the medical community on various forums, and the provision of an expert training for the usage of 3DP systems will further fortify the customer's relationship. (Shah et al., 2020)

Channels: Both, the company's website, and a call centre serve as direct communication channels. The company can also use various scientific conferences, and research projects as alternative channels. Face-to-face communication can be considered as another possibility (e.g. for direct sales of their products and services). (Shah et al., 2020)

Cost: The total cost of the company equals to the sum of manufacturing, marketing and sales, research and development, inventory, logistics, and services including training, personal assistance, and maintenance costs. (Shah et al., 2020)

Revenue streams: The company acquires its revenue by selling its printers and materials. Accessories adds a minor portion, but in terms of the revenue generation, services offered by HAGE3D will be of great importance in the future. (Shah et al., 2020)

The tools and the procedure adopted during the case study were helpful to identify the economic, social, and environmental aspects of a SBM (Osterwalder & Pigneur, 2010). A stakeholder map (Fassin, 2009) was used to highlight all the stakeholders during the process of creating a SBM but hardly contributed to value exchanges between other stakeholders than HAGE3D. On the other hand, the results generated by a VMT were stronger on social dimension than environmental dimension. This outcome was realized by using a VMT for the purpose of comparing 3DP technology with conventional manufacturing technologies in terms of value missed, and value opportunities. (Shah et al., 2020)

This thesis with the help of a newly developed SBM for HAGE3D using a BMC (Osterwalder & Pigneur, 2010) as the final outcome, addresses the following SDG i.e., SDG 1, SDG 3, SDG 4, SDG 9, SDG 12, and SDG 13 as mentioned in subchapter 2.2 in terms of an availability of products and services for people on low incomes, access to health care services of essential quality, indirect impact on job creation and youth employment, infrastructure and sustainability investments, research and development, resource efficiency of products and services.

CONCLUDING REMARKS (PART 4)

8. Conclusion

The thesis integrates the ideas of Oberg et al (2018) and Geissdoerfer et al. (2018), so as to create a SBM for a 3DP system manufacturer, and illustrates the practical implementation of different tools (Fassin, 2009; Bocken et al., 2013; Osterwalder and Pigneur, 2010), and addresses various SDG as mentioned in chapter 7. The research work initially summarizes the current knowledge on sustainability, SBM, and 3DP. It identifies the challenges, which are associated (in terms of mindset, triple bottom line, methods, tools, resources, technology innovation, and external relations) to the process of transformation towards a new SBM (Geissdoerfer et al., 2018). The study includes the procedure adopted during the research, and the usage and validation of various tools (Fassin, 2009; Bocken et al., 2013; Osterwalder and Pigneur, 2010). The research generates a holistic descriptive knowledge (Öberg et al., 2018) through a case study by creating a new SBM for a 3DP system manufacturer. The results specify that the use of simple and well-known tools, such as a stakeholder map (Fassin, 2009) is useful as a starting point to identify all the company's stakeholders. The practise of a VMT (Bocken et al., 2013) can support the company executives during the process of recognising a sustainable value, which integrates economic, social and environmental aspects of a business. The results of these steps allow users to clearly and practically integrate the generated data in a holistic manner using the BMC (Osterwalder & Pigneur, 2010) to create a SBM, and provide them with an outlook for the future steps.

8.1 Limitations

The implementation of holistic single case study procedure has a fundamental issue of generalizability, which cannot be generalized to other studies. In contrary multiple case studies explore the research questions in depth (Eisenhardt, 1989).

The case selected is limited to one type of SBM i.e., product-service system, and for one type of SBMI i.e., SBM diversification, where an additional SBM is created by a company without bringing any major changes to the existing business model (Geissdoerfer et al., 2018). Therefore, multiple case studies need to be carried out to test the applicability of these findings.

8.2 Recommendations for Future Work

The following future steps are recommended to further refine and improve this work, that can assist further challenges and solutions, in the process of sustainable business modelling and transformation. First, in order to discover this topic in depth, multiple case studies are required to be conducted, and also to test the applicability of the thesis's findings (Eisenhardt, 1989).

To further investigate the values exchanged by the stakeholders, a value network analysis (Biem & Caswell, 2008) should be applied on the outcomes of this work. The new business modelling tools such as the TLBMC (Joyce& Paquin, 2016) should be applied, which will further illustrate the social and environmental aspects of a business, in the process of creating a new SBM.

Further work should be carried out by selecting different case studies related to 3DP, that can fill the research gap on the other three types of SBM, and SBMIs (Geissdoerfer et al., 2018). In doing so more knowledge will generate, and will further help in developing a broad and better understanding of this nascent field of study i.e. a SBM for a 3DP system manufacturer.

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APPENDIX

A. Interview Questions

Q. Overview about the company HAGE i.e. history, vision, mission, business units and guiding principles?

Q. Why did the creation of HAGE3D occurred at first place?

Q. What were the external and internal factors responsible for this move?

Q. Who are your shareholder?

Q. When did you started working? What has been your journey so far?

Q. With HAGE3D, how the company new identity is reframed?

Q. How much time your first product took as a functional 3D printer?

Q. With HAGE3D product line targeting a new Industry (Medical) so how this decision was taken? Or still it's in consideration of which this case study is a part?

Q. Do you have any BM for HAGE3D, and is it the same as HAGE?

Q. Have you developed any of your own innovation matric for BM innovation during the last decades?

Q. When one triggers the term sustainability, what comes first into your mind? Or what does sustainability mean to you?

Q. As a company, do you feel pressure to be sustainable from any dimension?

Q. Moving from a conventional BM business model to a more SBM will require a sustainability strategy? Or this was never included in the company's overall strategy?

Q. What are the most important factors for you to consider, during the process of moving from a conventional BM to SBM?

- Sustainable value
- Proactive multi-stakeholder management
- Long term Perspective

Q. Have you reviewed the market segmentation of medical industry (locally and globally), and demographically which market will be on your priority?

Q. Have you done any rough value networking of your stakeholders?

Q. When we talk about market competitiveness, which drivers are important to you i.e. innovation or price or sustainability in terms of medical industry?

Q. Are you offering just a product or something more, i.e. a kind of product service system (e.g. digital app etc.)?

Q. What is HAGE3D market share in medical 3DP industry?

Q. Stakeholder perspective can be network centric or firm centric. What is important for you?

Q. Talking about design thinking process (i.e., to understand, observe, define, ideate, prototype, and test), do you consider sustainability in such process?

Q. What could be the biggest opportunities for the leadership of HAGE3D leadership within the medical market?

Q. What are the risks and challenges (internal and external) for HAGE3D to attain the initial goals, regarding its 3DP system for the medical sector?

Q. Would you like to add anything extra? Have we missed anything, that you would like to add?