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Cornerstones towards a successful implementation of AM technology

A qualitative phenomena-based study of the early-stage AM implementation process

Management and Organisation

Master's thesis

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Additive manufacturing (AM) can be described as potentially a disruptive technology that is studied mostly from the technological point of view eclipsing the people and managerial aspects. The lack of papers describing frameworks and ways to implement AM technology foreshadows the identified complexity of the process, however, makes it an intriguing and rewarding but also challenging research subject. The aim of this thesis is to contribute to the void of papers studying AM implementation from the organizational viewpoint and to create an implementation framework picturing the cornerstones of a successful AM implementation to shed light on this complex process, especially for practitioners entering the field of AM.

AM or more popularly 3D is a general term for technologies adding material together layer-upon-layer (SFS-EN ISO/ASTM 52900/2021). As a technology AM is not new, but it has continuously developed since the late 1980s and can be defined today as one of the Industry 4.0 technologies enabling e.g., high-added value through on-site and on-demand manufacturing of customized parts. AM can offer multiple benefits for an organization, but the implementation of AM includes also multiple challenges and questions to tackle before successful implementation, e.g., high investment costs and lack of competent workforce. Lack of AM knowledge together with the scarcity of AM implementation frameworks may result in false conclusions about the technology, its benefits, and challenges.

The thesis is performed as a qualitative phenomenon-based study in which the data is gathered through seven semistructured interviews of Finnish AM experts and analyzed through a thematic approach. As a result, the AM implementation is divided into the early- and later-stage implementation which the first is covered in this thesis. Consequently, the early-stage implementation is divided into three sub-phases: opportunity recognition, knowledge acquisition, and learn-by-doing. An AM champion, managerial support, and collaboration can be seen as building blocks of the early-stage implementation process of AM. Together, the three identified sub-phases and building blocks generate an accumulation of knowledge. The created framework aims to emphasize the essentiality of knowledge, especially during the early-stage implementation, and picture a complex process in which all parts are in continuous iteration between each other.

The data is gathered as a part of the Center for Collaborative Research´s (CCR) output at the University of Turku regarding the DREAMS (Database for Radically Enhancing Additive Manufacturing and Standardization) project funded by the members of the DREAMS consortium and Business Finland.

Key words: Industry 4.0, additive manufacturing, AM, 3D, knowledge, change management, resources, AM champion, collaboration, managerial support

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Lisääntyvää valmistusta (additive manufacturing, AM) voidaan kuvailla potentiaalisesti disruptiivikseksi teknologiaksi, jota on tutkittu pääasiassa teknisestä näkökulmasta sivuuttaen ihmis- ja johtamisnäkökulmat. AM-teknologian käyttöönoton viitekehysten vähäisyys enteilee tutkielmassa tunnistettua kompleksisuuden haastetta tehden aiheesta mielenkiintoisen ja palkitsevan, mutta myös haastavan tutkimuskohteen. Tämän lopputyön tavoitteena on avata monimutkaista prosessia alalle tuleville luoden käyttöönoton viitekehyksen, joka kuvaa tarvittavia kulmakiviä onnistuneeseen AM-teknologian käyttöönottoon. Tutkielma pyrkii vastaamaan tunnistettuun tutkimusaukkoon tarkastelemalla AM-teknologian käyttöönottoa organisaatiotasolla.

AM tai yleisesti ottaen 3D on yleiskäsite teknologioille, jotka lisäävät materiaalia yhteen kerros kerrokselta (SFS-EN ISO/ASTM 52900/2021). Teknologiana AM ei ole uusi, mutta se on kehittynyt 1980-luvun lopulta lähtien ja voidaan määritellä nykyään yhdeksi Teollisuus 4.0 teknologiosta mahdollistaen, esimerkiksi korkean lisäarvon kustomoitujen osien valmistuksen paikallisesti ja tarpeen mukaan. AM-teknologia voi tarjota organisaatiolle monia etuja, mutta sen käyttöönotto sisältää myös useita haasteita ja kysymyksiä, jotka on ratkaistava ennen onnistunutta käyttöönottoa. Tällaisia ovat esimerkiksi korkeat investointikustannukset ja puute osaavasta työvoimasta. Puutteellinen tietämys AM-teknologiasta yhdessä käyttöönoton viitekehysten vähäisuuden kanssa voi johtaa virheellisiin johtopäätöksiin teknologiasta sekä sen hyödyistä ja haasteista.

Tutkielma on suoritettu laadullisena ilmiöpohjaisena tutkimuksena, jossa aineisto on kerätty puolistrukturoiduilla haastatteluilla seitsemältä suomalaiselta AM-teknologian asiantuntijalta. Aineisto on analysoitu käyttäen temaattista analyysimenetelmää, jonka tuloksena AM-teknologian käyttöönotto on jaettu varhaiseen ja myöhempään vaiheeseen, joista ensimmäiseen keskitytään tässä tutkielmassa. Varhaisen käyttöönoton vaihe voidaan jakaa kolmeen osavaiheeseen: mahdollisuuksien tunnistaminen, tiedon hankinta ja tekemällä oppiminen. AM-champion, johdon tuki ja yhteistyö voidaan nähdä AM-teknologian varhaisen vaiheen käyttöönoton rakennuspalikoina. Yhdessä nämä kolme tunnistettua osavaihetta sekä rakennuspalikat saavat aikaan tiedon kumuloitumisen. Tässä tutkielmassa luotu viitekehys pyrkii korostamaan tiedon tärkeyttä erityisesti varhaisen vaiheen käyttöönoton aikana ja kuvaamaan monimutkaista prosessia, jossa kaikki osat ovat jatkuvassa vuorovaikutuksessa toistensa kanssa.

Aineisto on kerätty osana Turun yliopiston Center for Collaborative Research (CCR) -tutkimusyksikön tuotosta liittyen DREAMS-projektiin (Database for Radically Enhancing Additive Manufacturing and Standardization), jonka rahoittajina toimivat DREAMS-konsortion jäsenet ja Business Finland.

Avainsanat: Teollisuus 4.0, lisäävä valmistus, AM, 3D, tieto, muutosjohtaminen, resurssit, AM-champion, yhteistyö, johdon tuki

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1 Introduction

Kagermnann et al. (2013) describe the operational environment of manufacturing companies as competitive and fierce. In addition, Sonntag (2003) states that an important feature of competitiveness is the ability to adapt to a complex and rapidly changing environment. The integration of digital technologies like additive manufacturing (AM) and artificial intelligence (AI) into organizations´ existing production systems creates connectivity to the whole value chain and makes it possible to respond in novel ways to rapidly changing customer demands (Moschko et al 2023). The development of technology goes on continuously; therefore, the adoption of Industry 4.0 has become an essentiality for organizations to succeed in the market (e.g., Butt 2020: Martinez 2019). While the third industrial revolution is still in the beginning, the fourth revolution is already discovered (Michelsen 2020, 1–4), alongside the silhouette of fifth and even sixth industrial revolutions have appeared on the horizon (see Business Finland 2021; Sarfras et al. 2021). Even though the speed of technological change is fierce, in this thesis the emphasis is on Industry 4.0 and its one particular technology, additive manufacturing (AM). Turckan et al. (2022) are in fact recommending companies´ managements to take needed steps to benefit AM.

Additive manufacturing is a general term for technologies joining material together, layer-upon-layer, to create articles from 3D model data (SFS-EN ISO/ASTM 52900/2021). While AM offers multiple benefits for manufacturing organizations, for example, energy efficiency, environmental, economic, and social sustainability, flexibility, and design freedom (see e.g. Holmström et al. 2010; Kagerman et al. 2013; Mellor et al. 2014; Abubakr et al. 2020; Ghobadian et al. 2020; Gibson et al. 2021, 9; Rad et al. 2022; Turkcan et al. 2022) there are also challenges concerning particularly terms and definitions of AM (SFS-EN ISO/ASTM 52900/2021). In this thesis words additive manufacturing, AM, and 3D printing are used as generic terms. 3D printing or 3DP is used more commonly among the general public while additive manufacturing or AM is the terminology used by standards and experts (see e.g., Gibson et al. 2021, 8; Kamara & Faggiani 2021, 3; SFS-EN ISO/ASTM 52900/2021).

In addition to the challenges of AM, there is a lack of regulated implementation protocols. According to Butt (2020), the resistance to change and fear of the unknown are one of the major reasons to reject the implementation of Industry 4.0. Caputo et al. (2016) as well as Manesh et al. (2021) argue that problems related to additive manufacturing or generally Industry 4.0 have been studied nearly entirely from a technical viewpoint and only little from a managerial point of view. Furthermore, there is a lack of literature that would suggest managerial solutions or frameworks for digitalization and a gap in papers presenting successful integration of Industry 4.0 technologies in the operations or business cycle (Moeuf et al. 2018; Martinez 2019; Manesh et al. 2021; Priyadarshini et al. 2022). Martinez (2019) even pictures Industry 4.0 implementation as a utopia. He suggests exploring and writing about examples of particular digital transformations involved in Industry 4.0. Also, Priyadarshini et al. (2022) noticed as limitations of their study that a comprehensive and generalizable implementation framework for 3D is challenging to create.

To be stated, one more challenge related to the question of AM implementation is how to manage the transformation of digital manufacturing and position it within existing and new business models (see Deloitte 2019; Moschko et al. 2023). Because of the extent of the previously identified challenge, any closer observation of business models is excluded from this thesis. This thesis aims to address the gap presented above by creating an early-stage implementation framework of AM technology and contribute to understanding the implementation process in business management. While the importance of understanding AM technology, e.g., its applications and materials, is recognized, the focus is to create a general level understanding of the technology and its implementation process as well as its challenges and enablers. The sustainability aspect of AM is recognized but not highlighted in this thesis.

The purpose of this master´s thesis is to discover an early-stage implementation framework of AM at the organizational level. This research topic is studied through the main research question: How the early-stage implementation of AM is managed and organized at the organizational level? This is followed by one sub-question: 1) What are the challenges and enablers of the early-stage implementation process of AM? To address these questions and the aim of this thesis, chapter two introduces the technology and where it stands today in the big picture. Then, chapter three presents found frameworks for implementing AM technology as well as other aspects related to the implementation process. After the research method has been presented in chapter four, the next chapter concentrates on analyzing the gathered data by introducing the identified early-stage implementation framework and giving an overview of the building blocks of the implementation process. Finally, chapter six concludes the thesis and presents ideas for future research.

2 Building the base for the rediscovery of AM technology

2.1 Development of industrial revolutions

During the two centuries of sophisticated machines frequent, radical, and incremental changes have taken place in manufacturing systems and transformed manufacturing substantially (Butt 2020; Michelsen 2020, 1–4). Occasionally the evolutionary path is disrupted by radical changes which lead reigning manufacturing paradigm´s breakdown breeding a new form of manufacturing system as well as an industrial revolution, yet the change driving mechanism remains unknown (Michelsen 2020, 1–4; Manesh et al. 2021). The transformation of industrial manufacturing can be separated into four phases: the first, the second, the third, and the fourth industrial revolution. However, the development of technology goes on continuously, and already the fifth and even sixth industrial revolutions have been discovered (see Business Finland 2021; Sarfras et al. 2021).

Industrial revolutions have emerged over time and now we are living in interesting crossroads where one revolution is changing to another while future industries can already be seen. During the shift from Industry 3.0 to Industry 4.0 machines operationalize routines transfer into digital manufacturing in which machines can communicate and collaborate autonomously with each other (Manesh et al. 2021). The future of manufacturing and the landscape of Industry 4.0 is competitive and eventually, Industry 4.0 will overcome traditional manufacturing, Industry 3.0, based on mass production which is neither socially nor ecologically sustainable (Michelsen 2020, 6–7). However, even though technology can be the driver of change towards a more sustainable society, responsibility in manufacturing and business requires a change in people´s mindsets and ways of doing things.

Shortly described, the center of the first industrial revolution was mechanization through steam power and water, the second industrial revolution was based on mass production, labor division, and electrification while automation, IT, and electronics are characteristics of the third industrial revolution. The fourth industrial revolution´s focus is on the Internet of Things and cyber-physical systems while the fifth industrial revolution focuses on supporting and promoting ecologically and socially important values. (European Commission 2020.) Business Finland (2021) defines the sixth industrial revolution as: "Industry 6.0: Ubiquitous customer-driven virtualized antifragile manufacturing".

The opportunities for manufacturing companies have increased especially in the field of Industry 4.0 and circular economy (CE) because of the rapid change in information and communication technology (ICT) (Sahu et al. 2022). Abubakr et al. (2020) study points out that Industry 4.0 may be the one that boosts sustainable manufacturing which main pillars consist of economic, social, and ecological achievements. Industry 4.0 offers more sustainable, customized, and innovative solutions and products by reducing carbon emissions and resource consumption and enables high-added value and low-volume production in European countries (Mellor et al. 2014; Sahu et al. 2022). In addition, through Industry 4.0, resource productivity and efficiency can be continuous and delivered horizontally, e.g., by reducing operators in a logistic chain by printing parts with one machine covering the entire value network. Also, work can be organized by taking into account social and demographical factors and performing work changes into creative and value-added actions (Kagermann et al. 2013; Korpela et al. 2020, 31.) Furthermore, Sahu et al. (2022) add that Industry 4.0 offers companies self-organization capabilities, flexibility, sustainable resource management, and real-time monitoring.

According to the European Commission (2020), Industry 5.0 should be seen as a logical continuation and evolution to Industry 4.0, not as an alternative or replacement. More accurately industry 5.0 extends and complements characters of Industry 4.0 (European Commission 2021). The concept of Industry 5.0 is not based on technologies, but it involves values such as social or ecological benefits and human-centricity. Technologies, like autonomous robots, cloud computing, and additive manufacturing, are seen quite similar in Industry 4.0 and in Industry 5.0. (European Commission 2020.) Hence, because of the similarity of technologies and continuity between Industry 4.0 and 5.0 and on the other hand the contemporary overlapping of Industry 3.0 and 4.0 it might be hard to discover especially the breaking point of the fifth industrial revolution. Active agency is needed to accelerate the change towards more responsible manufacturing and society.

Even though, in the beginning, Industry 4.0 was focused on meeting the economic needs as well as ecological demands of so-called green production to achieve energy efficient and carbon-neutral industry like discussed above, however, Industry 4.0 has focused more on e.g., digitalization to better productions flexibility and efficiency and less on its initial principles of sustainability and social fairness (European Commission 2021). According to Butt (2020), the pandemic of COVID-19 has accelerated organizations´ planning phases toward Industry 4.0 while Sarfraz et al. (2021) are arguing that the pandemic has promoted the development of the fifth industrial revolution. In fact, Business Finland (2021) has created a foreseen path for Finland to move forward from Industry 4.0 to Industry 5.0 and to pursue the role of global leadership of Industry 6.0. Appendix 1 presents more detailed possible issues characterizing the path from Industry 4.0 to Industry 6.0.

According to Business Finland (2021) especially large Finnish companies have utilized Industry 4.0 technologies while in SMEs the situation varies. While Industry 4.0 has not yet conquered markets completely and replaced Industry 3.0 technologies, future paradigms of Industry 5.0 and Industry 6.0 have already been discovered (see Business Finland 2021; European Commission 2020). Based on customer demands and technological development, Business Finland (2021) estimates that development from Industry 4.0 to Industry 6.0 will happen in the next 10 to 15 years. However, it is important to notice that technological innovations develop industries as well as society through for example changing work roles (European Commission 2021) which can be assumed to require preparedness and prediction related to e.g., upskilling and training of the workforce at the organizational level but also the development of innovations and technologies require a different kind of education through institutions.

Kyläheiko and Maijanen (2020, 169) are naming as driving forces of Industry 4.0 transformation, for example, modularization, digitalization, robotics, additive manufacturing, artificial intelligence, global keen rivalry, and mass customization. Mellor et al. (2014) offer an answer to the challenges of increased flexibility and economic low-volume production via additive manufacturing. Also, digital information makes it possible at least for AM to design manufacturing products where the knowledge of the best high-tech experts exists and then flexibly produce the designed product where the demand is (Kyläheiko & Maijanen 2020, 170). Moschko et al. (2023) describe how the fourth industrial revolution is reshaping the manufacturing industry and how digitization technologies stimulate the manufacturing system´s digital innovations.

2.2 Continuously evolving AM technology, insights from the past and the present

In the late 1980s and early 1990s evolving technology, 3D-printing enabled something new and that is rapid prototyping (RP) (Simpson 2022b). However later, the term additive manufacturing was replaced by what used to be termed rapid prototyping. In a range of industries, RP is used to define a process for rapidly creating a part or system representation before final commercialization or release. The purpose of RP is to create something quickly and as an output develop a basic model or prototype from which further models and in the end the final product forms. (Gibson et al. 2021, 1–2, 9.) Back then RP made 3D-printing mainly applied for the fabrication of functional and conceptual prototypes (Mellor et al. 2014). Via rapid prototyping, the evolving technology got better, faster, and cheaper and the profits made from the 21st-century market pull were invested into the development of the technology. However, the popularity dropped until the technology had extensive attention because of the coming of metal 3D printing and the renaming of 3D printing as additive manufacturing. (Simpson 2022b.)

Improvements in technology´s material properties and accuracy have opened new realms like testing, tooling, and manufacturing. This strikes out the possibility of calling these parts only as prototypes anymore. Also, more reasons to move from the name RP to AM are firstly, the nature of manufacturing is seen as an additive approach (Gibson et al. 2021, 1–2, 9) and secondly, patents that have protected the technology, have started to become void in the 21st century (Sasson & Johnson 2016), in fact, the last FDM patent expired in 2009 (Kamara & Faggiani 2021, 32). Due to the latter development, now ASTM standards are using the term additive manufacturing instead of rapid prototyping. (Gibson et al. 2021, 1–2, 9; SFS-EN ISO/ASTM 52900/2021).

At least partly because of the strong legacy of rapid prototyping and multiple only recently expired patents, there have been challenges at least in the academic world to use one certain term about additive manufacturing. Words used as synonyms for additive manufacturing include 3D printing, 3DP, additive techniques, additive process, layered manufacturing, additive layer manufacturing, layer-based manufacturing, rapid manufacturing, rapid prototyping, freeform fabrication, additive fabrication, automated fabrication, direct digital manufacturing (DDM) and stereolithography (SL) (Mellor et al. 2014; Sasson & Johnson 2016; Attaran 2017; Gibson et al. 2021, 6–8; Kamara & Faggiani 2021, 2).

Currently, AM is driven by technology push, but it is more than recommended to refocus on the market pull which drove the adoption of 3D printing in the first place (Simpson 2022b). 3D has taken leaps forward and established itself in several industries. AM technologies are used in the engineering industry to create various applications as well as it is used in multiple other areas of society like as medicine, architecture, cartography, education, toys, and entertainment (SFS-EN ISO/ASTM 52900/2021), aerospace, jewelry, automotive, defense applications and for example, AM enables manufacturing of modules, dies, spare parts, tools and consumer products such as electronics, lighting goods and fashion (Mellor et al. 2014; Jin & Shin 2020; Simpson 2022a).

Compared to the time that it took to gain widespread use and take part in effective production from processes like machining and casting, the time that additive manufacturing has partaken is not that long, about 30 years (Simpson 2022a). Gibson et al. (2021, 9) describe what kind of hopes and future images there are about AM; some see 3D printing as revolutionizing product manufacturing and development while others even believe in a new industrial revolution if AM is followed to its eventual conclusion. However, Sasson and Johnson (2016) argue that rather than entirely reshaping the landscape of manufacturing or remaining in the margin, AM could be something in between. Also, Attraran (2017) brings forward that AM will not take over conventional manufacturing processes but transform niche areas. The common message of all these different future prospects of AM is that it has the potential to survive in the continuously changing environment.

According to Kamara and Faggiani (2021, 8–11), manufacturing and production are facing a paradigm shift because of the rise of AM technology and its unique techniques and processes. However, Simpson (2022a) states, that AM stands on in its infancy compared to other more traditional manufacturing processes. Fundamentally dissimilar economic drivers when compared to traditional manufacturing and subtractive processes emerge from AM´s flexibility, 3D model data, and the manufacturing process itself, adding layer upon layer. In fact, because of the 3D model data, the high-cost tooling is no longer needed, and joining material layer upon layer enables the reduction of waste and scrap. In addition, AM´s additive nature releases at least from some limitations of traditional manufacturing processes, there is a geometric freedom when designing products for processes of AM (Mellor et al. 2014).

When comparing AM to most other production processes, they would need multiple and iterative steps to be carried out. Using conventional methods, when the number of features or even a simple change comes into the design, the number of needed steps and time increases significantly. But when there is a change in the design of a part that will be produced via AM, the change is implemented during the formative step of product development and the time used is relatively insensitive. Likewise, resources and the number of processes can be reduced via AM. (Gibson et al. 2021, 9.) In fact, Attaran (2017) has identified five key benefits (speed, quality, cost, impact, and innovation/transformation) of AM and multiple advantages compared to traditional manufacturing (see Table 1).

Table 1 Advantages over traditional manufacturing (Attaran 2017)

Areas of application of AM	Advantages of AM over traditional manufacturing
Rapid Prototyping	Reduce time to market by accelerating prototyping Reduce the cost involved in product development Making companies more efficient and competitive at innovation
Production of Spare Parts	Reduce repair times Reduce labor cost Avoid costly warehousing
Small Volume Manufacturing	Small batches can be produced cost-efficiently Eliminate the investment in tooling
Customized Unique Items	Enable mass customization at low cost Quick production of exact and customized replacement parts on site Eliminate penalty for redesign
Very Complex Work Pieces	Produce very complex work pieces at low cost
Machine Tool Manufacturing	Reduce labor cost Avoid costly warehousing Enables mass customization at low cost
Rapid Manufacturing	Directly manufacturing finished components Relatively inexpensive production of small numbers of parts
Component Manufacturing	Enable mass customization at low cost Improve quality Shorten supply chain Reduce the cost involved in development Help eliminate excess parts
On Site and On-Demand Manufacturing of Customized Replacement Parts	Eliminate storage and transportation costs Save money by preventing downtimes Reduces repair costs considerably Shorten supply chain The need for large inventory is reduced Allow product lifecycle leverage
Rapid Repair	Significant reduction in repair time Opportunity to modify repaired components to the latest design

To remind and avoid possible misunderstanding between the term additive manufacturing and one of its applications named rapid prototyping, additive manufacturing term refers to the additive process or the technology while the term rapid prototyping points to the application of AM. Rapid prototyping was the first application of 3D and helped to innovate, increase time-to-market, and create prototypes of finished products which are further tested before starting a mass production. (Attaran 2017.) In addition to the advantages of AM over traditional manufacturing described above, there are also new behavior, skill, and knowledge requirements for workers using AM while classic manufacturing work categories (process, design, material, compliance, and testing) remain the same (Kamara and Faggiani 2021, 8–11).

Each AM system has distinctions but also similarities and all AM processes are related when it comes to their additive nature of manufacturing, each 3D printing process shares the additive foundation of building components (Mellor et al. 2014). Gibson et al. (2021, 3–4) summarize that most AM processes, at least to some degree, involve eight steps; conceptualization and CAD, conversion to STL, STL file transfer and manipulation on AM machine, machine setup, build, part removal and clean up, part´s post-processing and finally application. In theory, the only inputs AM requires for production are raw materials and CAD data (Mellor et al. 2014). Attaran (2017) also argues that most commercial 3D printers function similarly; computer-aided design (CAD) translates the design into a three-dimensional model which is then sliced into various two-dimensional patterns that guide the 3D printer to deposit material layer by layer.

Nowadays AM is referred to as disruptive technologies that are transforming the way of setting up new businesses and designing products (e.g., Deloitte 2019; Gibson et al. 2021, 9). In fact, because of digital production design, the line between products and services is losing its importance, and manufacturing firms also become service providers. This integration of services and manufacturing can be called servitization. (Kyläheiko & Maijanen 2020, 170.) According to Müller et al. (2018), Industry 4.0 enables servitization which makes possible new forms of value capture and new services to organizations' value offers. In fact, early investment in 3D printing might allow a manufacturer to become a regional supercentre. 3D printing could reduce production variability for manufacturers with diverse products and complicated bills of materials by improving the efficiency of mass production and developing AM service manufacturing business. Manufacturers adopting 3D printing, co-located manufacturers, may become on-demand producers of diverse products. Production variability can be seen as a driving force leading to traditional manufacturing and AM`s co-location. (Sasson & Johnson 2016.)

2.3 AM technology, a friend or foe

Despite the complexity of a part to be built, via AM technology building is mainly performed in a single step. AM´s speed advantage does not refer only to the time it takes to build a part, but also to speeding up the whole process of product development due to the use of computers throughout the process. AM can be used to simplify or even remove multistage processes and with the addition of supporting technologies like grinders, polishers, or drills AM has a great potential to produce a wide range of different parts with different features (Gibson et al. 2021, 9). In addition to benefits, critical success factors regarding additive manufacturing are collaborative and integrated product design, step-by-step implementation, and software-printer compliance (Rad et al. 2022). Also, according to Frizziero et al. (2021), AM helps technical and styling product developers maintain timelines and save time and costs by potentially avoiding later redesigning steps. The industrial design of the product or part can be seen as the most important step in a product´s lifetime because it controls the costs, the production time, the style, and the last product´s impact on the market. There are multiple benefits listed in the literature about AM technology. Examples of found benefits have been categorized and summarized into four main sections in Table 2.

Table 2 Examples of the benefits of AM technology

Benefits of AM technology	
Design and the product	Improved product strength and functionality (Neuner & Lang 2019) Seamless products (Gibson et al. 2021) Product/design customisation (Holmström et al. 2010; Neuner & Lang 2019; Gibson et al. 2021; Rad et al. 2022) Greater design freedom (Neuner & Lang 2019)
Production process	Reduced assembly time for complex components / time efficiency (Neuner & Lang 2019; Frizziero et al. 2021; Gibson et al. 2021) Localized production (Neuner & Lang 2019) Reduction of process steps (Holmström et al. 2010; Neuner & Lang 2019; Gibson et al. 2021) Mitigation of wastage (Holmström et al. 2010; Nuener & Lang 2019)
Supply chain	Green / optimized supply chain (Rad et al. 2022) Potential for simpler supply chains; shorter lead times, lower inventories (Holmström et al. 2010) Decreased reliance on traditional suppliers (Neuner & Lang 2019)

Other	More streamlined, cleaner and versatile manufactories (Gibson et al. 2021) Integration and improved research and development (Neuner & Lang 2019; Rad et al. 2022) Competitive advantage (Kyläheiko and Maijanen 2020, 172; Turckan et al. 2022)

Even though AM has multiple benefits, it also has challenges. One challenge is the excitement concerning AM technology and its various benefits. To avoid this challenge, expectations need to be set in terms of the possible obstacles and difficulties while creating the perfect 3D-printed part. (Neuner & Lang 2019.) As for Rad et al. (2022), have identified costs, design, and production team management, restructuring the supply chain, availability of printing materials, and continuous customization and design complications as AM´s challenges. Attaran (2017) points out AM´s obstacles to rapid growth size restrictions, production time, cost, and regulations which can be also seen as a barrier to AM´s implementation. Size restrictions mean that a 3D printer can print only smaller objects than the casing of the printer. If the production time cannot be improved, large quantities will be produced through traditional manufacturing. The cost of 3D printing and its materials will decrease while the technology evolves and filament (e.g., plastic filament produced utilizing used plastic bottles) production and alternatives increase competition. Regulation is needed to prevent social and commercial implications, but it does not always follow the speed of innovation.

Besides also multiple challenges of AM, Turkcan et al. (2022) have found a linkage between additive manufacturing and competitive advantage: manufacturing firms need to use AM technology to remain competitive. They even describe AM as the new competitive weapon. Through AM technology, new product development performance increases which contributes to competitive advantage. Also, Oltra-Mestre et al. (2021) state that well-implemented Industry 4.0 technology supports the company´s competitiveness. However, while the competitive advantage is a benefit of AM, the main challenge for organizations according to Kyläheiko and Maijanen (2020, 172) is organizational renewal because of radical uncertainty. Organizations that want to maintain their competitive advantage need to be able to transform and reorganize their operational manufacturing routines, skills, and capabilities as well as resource base, especially knowledge, in a cost-efficient way (Kyläheiko & Maijanen 2020, 170). According to Müller et al. (2018) research SMEs recognize the need to consider Industry

4.0 technologies if they wish to stay competitive. When the needs and expectations of customers are getting higher, the advantages of AM are getting more important. AM technology is needed for quickly changing needs and demands coming from customers but also from the environment. (Turckan et al. 2022.)

Unruh (2018) argues that 3D printing can be seen as a key factor in the emergence of circular economy (CE) and so forth in environmentally sustainable manufacturing. Environmental sustainability benefits are environment protection and reduction of CO2 emission through product life extension and the technology itself reduces waste. Through achieving these environmental sustainability benefits of AM, a company can also achieve CE goals. (Priyadarshini et al. 2022.) Also, referring to Carroll´s and Shabana´s (2010) article, additive manufacturing might have a connection to CSR. For example, Rad et al. (2022) offer one of AM´s benefits as improved environmental performance, a “green supply chain”, Abubakr et al. (2020) state that AM reduces manufacturing steps succeeding in the reduction of energy and waste consumption and Kagerman et al. (2013) are finding AM as a factor of employees’ work-life balance. However, while also Ghobadian et al. (2020) acknowledge AM´s great environmental and economic promise and social benefits, they remind that many promising technologies have failed in their formative phase, which AM is right now, by not reaching high adoption of the technology. In addition to the uncertain future of AM, Turkcan et al. (2022) state that there is a lack of empirical evidence about how AM technology creates value for companies and according to Priyadarshini et al. (2022) research on AM implementation for sustainability purposes is underdeveloped.

While for example Attran (2017) as well as Kamara and Faggiani (2021, 3) bring forward the possibility of a prosperous future of additive manufacturing, especially through improved and distributed product manufacturing and shortened time to market, Kamara and Faggiani (2021, 3) remind that continuing growth of AM over the next decade may give a rise for two key challenges to AM; firstly focusing too hard on aspects of low-volume production and prototyping that other benefits of the AM process are dismissed and secondly possibilities of evolving technologies and processes are difficult to utilize because of the lack of skilled workforce. In addition, Deloitte´s (2019) insight emphasizes overcoming multiple challenges of AM related to scaled adoption of e.g., end-use parts. These challenges include e.g., lack of competent workforce and IT standards related to digital threads of the design and manufacturing processes.

Contrary to the challenge of the lack of skilled workforce named above, Attaran (2017) brings forward AM´s autonomous abilities in the future in which 3D printers could work fully autonomously and ensure errorless design without the involvement of a human. While the future development of AM technology might aim for its autonomous usage when supervision of the printing process itself is no longer needed, it is presumable that people play an irreplaceable role in the decision-making of whether to adopt AM technology in the organization and how to implement it. Also, as described in the coming chapters, designing printed products or parts and selecting appropriate machines and materials require human expertise, collaboration, operating in the ecosystem, and not forgetting mutual interest in developing additive manufacturing.

2.3.1 A critical view towards AM implementation

Sonntag (2003) reminds that new technology might not be the best strategic decision for an individual organization automatically but at some point, an organization needs to replace old technology with a new one and comply with its different capabilities, new ways of organizing production, and changes in product markets that transform competition and future paths. When an organization does not have mechanisms such as implementation process and strategy formation, operational decisions are executed through an organization´s rules that are built on past experiences, which might not be the best fit for the new technology. Implementation of advanced manufacturing technology often ends in failure because organizations are not taking the necessary structural and organizational changes into account. From the recourse-based view, implementation of AM should be seen as a structural investment that will firstly build new capabilities for manufacturing and secondly create new business opportunities as a technology-push strategy (Mellor et al. 2014). Deloitte´s (2019) insights picture well how the cost model of AM differs a lot from conventional manufacturing’s cost factors, in AM the cost model forms from the series of workflow steps which each has its own cost factors.

There are multiple things to consider and understand when even thinking about the possibility of AM in a company, whether to move from conventional manufacturing to AM or not. If the traditional way is working, parts are distributed on time, costs are reasonable, the tooling investment is justified by production volumes, the supply chain is working, channels function efficiently, customers are satisfied and they are not willing to pay for personalization nor perks of lightweight parts that can solely be made with AM, then why is AM worth of the investment? The answer according to Simpson 2022b is clear, if it is not broken, do not change it. Also, Kamara and Faggiani (2021, 4) remind that the change to AM demands extensive capital investment, and Müller et al. (2018) point out that the novelty of Industry 4.0 technologies makes implementation expensive especially for SMEs. However, Attaran (2017) reminds that not only machines are expensive but in addition printable materials required for printing are high-priced and Gibson et al. (2021, 637) recognize the significant investment in employee training. According to Müller et al. (2018), Industry 4.0 is seen as expensive in the short term because it takes time to reveal the benefits of the technology.

While manufacturing companies might be slow to change and averse to taking risks because of the investment in current infrastructure, required comprehensive change in an organization, and costs to retool, AM´s variability in technologies, available applications, and materials makes it even more difficult for an organization to make a decision to move towards additive manufacturing. However, through knowledge of different variations of additive manufacturing and each benefit an organisation is easier to appraise and select among multiple opportunities. (Kamara & Faggiani 2021, 22–23, 154.) In addition, an organization´s decisions considering the strategic use of production technologies can be seen as instruments that shape the company´s future. (Sonntag 2003.)

3 Theorizing the implementation of the AM technology

3.1 How to respond to Industry 4.0 and AM technology

As Müller et al. (2018) have indicated, there are different reasons as well as different company backgrounds to adopt or consider adopting AM. When Industry 4.0 is implemented in an integrated way and systematically, it impacts positively the organisation´s competitiveness through achieved product characteristics, such as product function and meaning, and operations process performance (Oltra-Mestre et al. 2021). Müller et al. (2018) have identified different strategies to respond to Industry 4.0 technologies (see Figure 1). For example, full-scale adopters are persistent to profit from new technology and see a possibility in Industry 4.0 either to remain or to become industry leaders. It is noticeable that this group of proactive implementors of Industry 4.0 technologies is eager to support also other companies to implement the technology. Through Figure 1 an organization can consider their own approach regarding Industry 4.0 and AM technology.

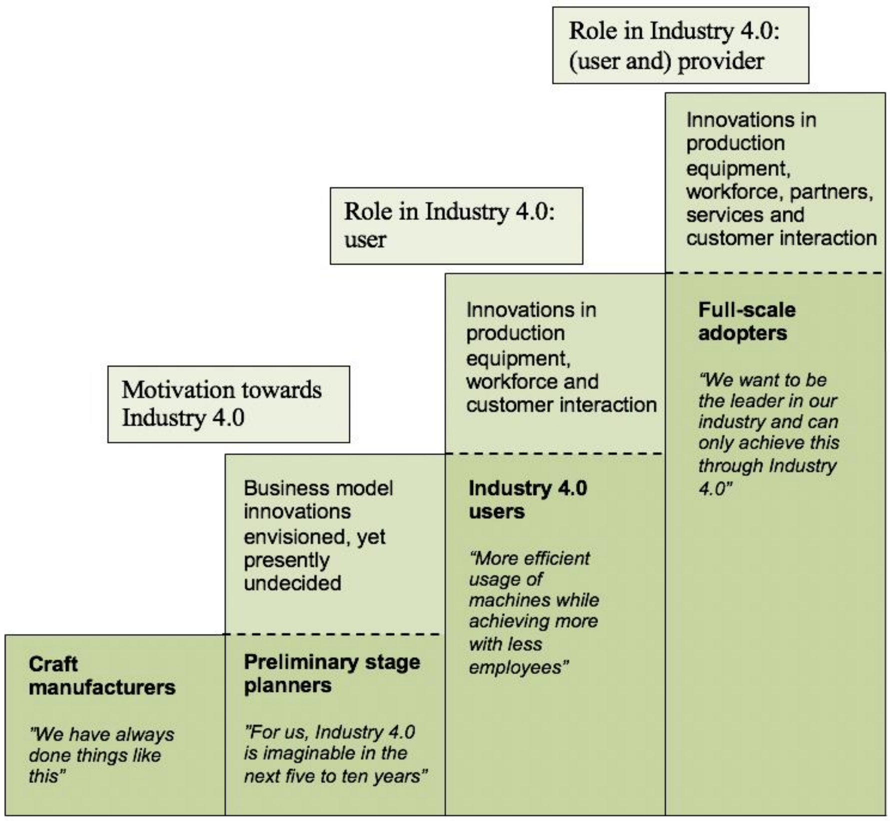


Figure 1 Stage model of manufacturing SMEs in the context of Industry 4.0, adopted from Müller et al. (2018)

Related to the previous stage model of Industry 4.0, Deloitte´s (2019) report suggests how the adoption of AM will increase when the technology continues to develop, and it moves from the disruptive technology used by innovators to a common method of production. However, there are a few other problems worth mentioning when concerning the move towards AM. For example, the lack of technical standards displays an adoption barrier for AM; Some characteristics of AM are a consequence of its immaturity which managers should be aware of when making an implementation decision. In addition, connecting to the question of the maturity level of AM technology, there might be a psychological barrier to implementing AM because of an inherent legacy of rapid prototyping with the AM system: management sees the technology as being suitable for applications of RP. (Mellor et al. 2014.)

Butt (2020) states that technologies of Industry 4.0 demand integration throughout a business to take advantage of their benefits. After reviewing 3D as a manufacturing approach and making a decision to move forward with it, a critical step an organization must do is to develop, as a part of the business model, a vision and strategy for AM (Kamara & Faggiani 2021, 154–155). To successfully implement AM technology, besides the adoption decision of a new manufacturing technology company needs to change tasks, work practices, and structure. To gain a competitive advantage from implementing AM, an organization's ability to combine the benefits of AM with the business strategy is emphasized. (Mellor et al. 2014.) However, when adopting new technology, an organization needs to understand that compromises need to be made and consider them when making a business plan. In general, when adopting AM, material and machine costs remain high, the process speed is rather slow, and the range of material remains low. (Sonntag 2003; Mellor et al. 2014.) The technology's potential benefits such as the reduction of scrap, inventory, and assembly steps as well as reduced lifecycle costs should be weighed against increased costs (Deloitte 2019).

When implementation of AM progresses, it must be ensured that the created AM vision and strategy are achieved through measuring and monitoring key indicators. (Kamara & Faggiani 2021, 154). In addition, to succeed in adopting AM, the implementation framework needs to cover both, change management strategies as well as technical education (Neuner & Lang 2019). The key here is to select applications matched with the manufacturing, business, research, and development activities and goals. In the ideal situation, a company will identify metrics or key performance indicators before implementation of AM to compare measurements of pre-and -post-implementation. (Kamara & Faggiani 2021, 154–155.) Also, Butt (2020) highlights tracking different metrics. According to Mellor et al. (2014), strategic alignment of the business, R&D, and manufacturing strategy must precede AM´s implementation. The benefits of the technology have to be linked to the capabilities coming from the business strategy.

3.2 Implementation of AM through managing change

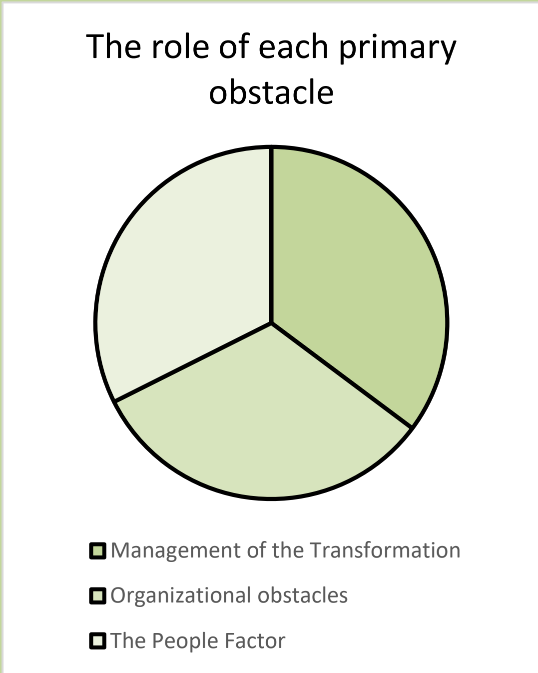
Butt (2020) states that a smoothly functioning business process is crucial for a successful business. Although business process management (BPM) offers multiple benefits, such as cost and waste reductions, technology integration, and employee satisfaction as well as cross-department synergy, its inaccurate implementation may lead to failures (Butt 2020) or perhaps stop the whole process if implementation barriers cannot be defeated. Priyadarshini et al. (2022) have studied the implementation of AM in the context of a circular economy and identified three top barriers to AM adoption; 1) ´High investment costs of printing materials´, 2) `Lack of knowledge about AM and its environmental benefits´ and 3) `High investment for R&D and training´. To facilitate sustainable operations organizations must overcome these barriers during the implementation process of AM. Through BPM, an organization can organize an end-to-end business strategy by fracturing barriers between different departments, leveraging a company´s performance, and offering an organized method to integrate changes (Butt 2020).

To guarantee implementation success leaders need to develop a change management strategy including the acquisition of an AM system as well as training of employees. It is worth mentioning that there is no one right solution to create a change management strategy; changes vary depending on the size of the organization, selected AM applications, and technology adopted. (Kamara & Faggiani 2021, 154, 158.) According to Martinez (2019), there are two main prospects on paths for organizations: radical change and the continuous improvement philosophy. However, there can be identified three areas concerning AM implementation that are relevant almost in every case; 1) AM system and support acquisition, 2) development of employees' skills and knowledge, and 3) supporting AM implementation through redesigning or creating needed processes and workflows (Kamara & Faggiani 2021, 154, 158). According to Neuner and Lang (2019), the role of change management strategy is highlighted because there can be many obstacles in the implementation of AM, for example choosing the wrong AM process or material or realizing the fact that a certain component design is suited more properly to traditional manufacturing.

According to Mellor et al. (2014), the success of AM implementation depends on the organization´s ability to introduce the benefits of AM as a manufacturing process in a balanced and clear way. As a potentially disruptive technology AM challenges experience, practice, and understanding of traditional manufacturing. Rather than a technical or strategic challenge an organization might encounter during the implementation process of AM, is in fact human-related challenge. The difficulty is to increase knowledge about AM among manufacturing engineers and reduce resistance towards 3D technologies. Change management must find a way to change the traditional manufacturing mindset, especially engineers´ ways of thinking, towards a fresh perspective. (Neuner & Lang 2019.) However, Gehrke et al. (2016) notice that daily demands in business and operations create a challenge to give time for employees to pursue innovations. Proper implementation of AM encourages engineers to think outside of the box of traditional manufacturing to for example reduce material wastage (Neuner & Lang 2019).

Gehrke et al. (2016) study points out that the reasons for the slow implementation of Industry 4.0 include the lack of different kinds of tools for decision support, methods, and concepts together with the complexity of the change and transformation process. One challenge for implementation is the lack of information sharing and collaboration between different departments and actors, especially inside the organization. In fact, Mellor et al. (2014) suggest that the implementation of AM needs to be studied in different organizational contexts and supply chain scenarios. They have created a framework proposing that both internal strategy and external forces encourage the consideration of AM as a technique of manufacture. The framework´s purpose is to assist managers in the AM implementation process. The approach to AM implementation is authorized by five different constructs of factors: strategy, technology, organizational change, systems of operations, and the AM supply chain. The study of Gehrke et al. (2016) indicates that in the implementation of Industry 4.0 technologies primary obstacle is in the managerial angle of digital transformation. They discovered three challenge patterns together with nine equivalent challenges presented in Table 3. All nine challenges they found concern issues in management in manufacturing organizations.

Table 3 Top challenges of the digital transformation of logistics and manufacturing, adopted from Gehrke et al. (2016)

Management of the Transformation • Lack of tools, methods, and concepts for process digitization • Unclear migration scenarios • Management of the transformation lacks structure and direction	
Organizational Obstacles • Organizational structure of the company • Lack of cooperation and collaboration at the transformation • Time and budget constraints for development teams	
The People Factor • Low awareness, acceptance, belief, interest • Unsupportive culture, mindset, trust • Low qualification, education, competencies	

It is interesting how each presented implementation approach in this section brings a new viewpoint to think the implementation of Industry 4.0 technologies or particularly 3D printing. Gehrke et al. (2016) present a strong view of organisational issues concerning mostly management and their input during the change process and BPM takes a more holistic perspective to implementation by concerning different areas of operations like management, technology, strategy, and metrics. The Framework of Mellor et al. (2014), which is also used as a basis in Kamara and Faggiani´s (2021) description of AM implementation, takes an even broader view than BPM including also external forces and supply chain. And finally, barriers from the circular economy point of view do not mention at least directly management viewpoint which has been present in all other figures or tables of this section. So, the question remains, what are in fact the most critical barriers or factors when implementing AM technology?

According to Butt (2020), there are no regulated protocols to implement Industry 4.0 technologies. Implementation strategy should be adapted depending on the business´s nature, its interdependencies, and complexities to guarantee a favorable outcome. However, he notes that through ineffective management of the framework like BPM, businesses may have considerable losses in revenue, intellectual property, and customers. In addition to this statement, it must be underlined that Mellor et al.´s (2014) framework is created for managers to have guidance during the organizational change, and implementation of AM technology. Even though this thesis concentrates on the early-stage implementation of AM, understanding the entity can be seen as essential. To support the big picture, Deloitte (2019) has outlined a four-step approach for the effective implementation of AM at a large scale. First, challenges need to be identified and analyzed whether AM fits the organization, and then a business case for AM should be created by examining the impacts along the whole supply chain and product life cycles. Then before scaling a roadmap including pilots, timetable, and needed measurements needs to be created. And finally, organizational shift by generating a positive mindset inside the company should be done to help reach critical masses inside the company. In this final stage also partnerships outside the company in the AM ecosystem should be identified.

3.3 AM´s demand for expertise

Sociotechnical System Theory (STS theory) can be applied to study digital transformation because digital transformation calls for a holistic approach to organizational change (Imran et al. 2021) which STS theory includes through connecting technical and social aspects (Sony & Naik 2020). Sony and Naik (2020) propose connecting STS theory to Industry 4.0 for sustainable implementation. It is suggested that Industry 4.0 will not decrease the need for human interaction but required skills are changing towards specialisation. Technology and social relations are merged. Also, according to Müller et al. (2018), while Industry 4.0 technologies can compensate at least to some point inexperienced manufacturing employees, they cannot compensate lack of professionals, especially in manufacturing and IT. In fact, vice versa, industry 4.0 amplifies the demand for experts. Priyadarshini et al. (2022) identified a skilled workforce and the need for R&D as the bottlenecks of AM. Through a continuous process of workforce acquiring and training as well as R&D investments the obstacles can be defeated and the perks of AM´s environmental sustainability achieved.

According to Mellor et al. (2014) review, AM significantly impacts product designing, and hence designers themselves: designers' understanding of designing for AM can be seen as an influential factor in the implementation process of the manufacturing technology. AM´s additive nature requires the development of new practices and design tools. New technologies challenge traditional strategic options and norms. Adopting AM as a new manufacturing technology for the company, demands engineers and designers to think in a new way design for manufacturing (DFM). Products need to match with processes and users of AM need to understand new process capabilities. This requires a skilled workforce. Also, Gibson et al. (2021, 639, 540–541, 555) identify the need for training of e.g., engineers and designers.

Müller et al. (2018) have studied the implementation of Industry 4.0 technologies in SMEs across business model elements which are value creation, value offer, and value capture. Different challenges were identified across business model elements like high investment in machines, personnel, and technical training versus customers' unwillingness to pay more, concerns about data security, small batch sizes, standardization, and losing customers. It was revealed that SMEs lack the expertise to deal with these challenges when implementing 4.0 technologies. In fact, according to Mellor et al. (2014) literature review, when implementing new manufacturing technology, the company´s size is a critical factor in understanding the process because the implementation approach is likely to differ between an SME and a large company. Moreover, an organization´s structure seems to be the key factor to implement manufacturing technology successfully, whereas without starting with re-designing organizational processes and structures a company confronts difficulties.

3.4 Collaboration and communication

Manufacturing systems use natural, social, political, and cultural resources like knowledge, regulation, legislation, and ideology (Michelsen 2020, 4). To implement Industry 4.0 successfully, companies need to for example collaborate with several enterprises through value networks and comply with law. Also, existing legislation needs to adapt to new innovations and companies need suitable instruments, e.g., model contracts and self-regulation initiatives, like auditions to handle challenges like liability issues. (Kagermann et al. 2013.) AM has an ever-evolving nature that calls for the continuous need for R&D (Priyadarshini et al. 2022). For example, industrial production managers and manufacturing engineers are needed to either replace already existing methods or to organize the incorporation of AM in current production processes. Also, improved collaboration and communication across the company are required to guarantee a solid connection among technicians, technologists, design and manufacturing engineers, and operators. (Kamara & Faggiani 2021, 19.) However, collaboration and communication are needed also externally, especially in SMEs`. Industry 4.0-related ecosystems are crucial especially for small and medium-sized (SMEs) organizations because of their limited resources to acquire the required knowledge and capabilities to develop complicated solutions by themselves (Benitez et al. 2020). Müller et al. (2018) state that challenges and lack of expertise might work as a booster for pushing back boundaries to create hubs and ecosystems to learn and develop together.

Also, Martinez (2019) emphasizes collaboration during a technological change in an organization and proposes an individual digitalization path as an individual venture of an organization. Digitalization paths are individual for each organization, but they share comparable and complementary aspects that are not generalizable but encourage learning from others. Continuously, implementation of AM requires increased collaboration with customers and suppliers and the machine seller´s support during the implementation process is a critical factor in successful implementation (Mellor et al. 2014). In fact, according to Zairi´s (1998) empirical research, the level of intensity of user-supplier interaction processes is related to the complexity of AM technology innovation. For example, there are two supply chains in the implementation process of AM. One that includes a supply chain from the machine seller to the buyer of the technology and one that covers the company, in which the machine has been bought (Mellor et al. 2014).

There are different kinds of strategies to pilot AM technology and it requires collaboration with different groups inside and outside the company (Deloitte 2019). Selecting an AM pilot project carefully through clear business needs is important to make sure that the first AM project illustrates 3D´s value-additive capabilities in the particular context of the organization and generates prompt economic value (Kamara & Faggiani 2021, 22). One can start a pilot test by communicating it throughout the organization and this way organization is able to learn about the technology and examine the best applications for the organization. An organization can also acquire an AM system, install it for the use of employees, and allow them to find the best applications. Other pilot strategies would be consulting with a service bureau or a regional university AM consortium or seeking insights from reliable machine sellers and developing a sensing path. (Kamara & Faggiani 2021, 154.)

4 Methodology

4.1 Introduction to the research strategy

As already stated, the thesis aims to discover a path toward a successful AM implementation by identifying early-stage implementation enablers and challenges at the organizational level. Additive manufacturing is one of the Industry 4.0 technologies hence it has been developing already for 30 years (see e.g. Butt 2020; Simpson 2022b). AM is a general term for technologies that layer-upon-layer join material together from 3D model data (SFS-EN ISO/ASTM 52900/2021). Even though the technology itself has been studied and developed over the years, research from implementation, organizational change, and the managerial point of view has remained remote (see Caputo et al. 2016; Moeuf et al. 2018; Martinez 2019; Butt 2020; Manesh et al. 2021.) This thesis represents qualitative business research that applies a thematic explanatory approach to address the gap described.

The practical purpose and aim of the analysis and this thesis are to find an understanding of the early-stage implementation process of AM as well as to contribute to the existing literature. The analytic purpose is to explore and identify e.g., possible steps and challenges and perceive recurring patterns during the implementation. Like this thesis, also qualitative research has a mutual aim to understand issues of reality (Eriksson & Kovalainen 2008, 4–5). Doh (2015) defines that phenomenon-based research starts from a contemporary issue of the real world which in this connection could be defined as incomplete knowledge of AM implementation at the organizational level.

There has been iteration between the literature and the collected data which implies that this study follows the abduction logic which takes place during the repeated interplay between induction and deduction (Locke 2009). The inductive research process starts from empirical materials like particular cases and proceeds to theoretical results and general conclusions while in the deductive process, the theory is regarded as the first source of knowledge, like a general argument which is followed by empirical research and conclusion (Eriksson & Kovalainen 2008, 22–23; Mingers 2012).

To open the iteration between the theory and data gathering, first, it was surveyed what kind of literature there is about AM implementation. Secondly, the nature and development of AM technology had to be discovered at a general level to understand the lack of managerial or human points of view in the implementation process. Then semistructured interview questions were created to match the needs of CCR´s handbook as well as this thesis´s research questions. Therefore, there has been a dialogue between composing the literature and analyzing the empirical material. According to Mingers (2012), abduction logic explains the phenomenon that deduction or induction separately cannot offer while Guest et al. (2012, 37) argue that explanatory qualitative research uses abduction logic.

4.2 Presenting the experts and represented organizations

This study aims to shed light on an early-stage implementation of AM at the organizational level. The described phenomenon is studied through seven expert interviews referred to as E1 to E7 which mostly are based on experts' experience gathered in their current or previous workplaces. Represented organizations by the experts can be divided into two categories: AM user companies and AM service providers. Four of the seven companies can be seen as AM service providers because they offer for example education or consulting services about AM technology as well as they design and print 3D parts. The last three organizations of the total seven can be called AM users. However, these three AM user organizations are quite different from each other referring to their way of operating with 3D. In E5´s organization AM technology has completely replaced one of the old processes and is used as an auxiliary activity, while the organization and more specifically the department E6 works at, AM printed parts are purchased and mainly used for prototyping. In addition, E7 represents an organization in which AM can be seen as a start-up inside the organization aiming to combine each department to understand and use AM technology.

Furthermore, to divide represented organizations by the experts into the previous two categories, E1´s, E2´s, and E3´s organizations are so-called born digitals while other represented companies have implemented AM as a new operation mode alongside other functions. As additional information company sizes have been classified through the number of employees; micro enterprises (less than 10 employees), SMEs (over ten but less than 250 employees), and large enterprises (250 or more employees) (see e.g., OECD 2023). Also, it is noteworthy to highlight a significant actor in the field: the Finnish Additive Manufacturing Ecosystem (FAME), which was established in 2020 to operate in the Finnish field of AM technology for example to connect Finnish top-know-how companies and share information, increase the use of AM in Finland, advance AM education as well as boost co-creation and co-utilization (FAME: About 2023). Each of the represented organisations, except the one E5 represents, are part of the FAME. Table 4 presents detailed information about each organisation in which interviewed experts at least during the interviews worked at as well as their professional titles in those companies.

Table 4 Information about the interviewed experts and their companies

Identity code	AM user	AM service provider	Member of the FAME	Company size	Professional title
E1		X	X	SME	CEO
E2		X	X	micro	CEO
E3		X	X	SME	Managing Director
E4		X	X	large	Department Manager
E5	X		-	SME	Quality Manager
E6	X		X	large	Manager, Engineering Analysis
E7	X		X	large	Innovation Manager

Based on the gathered information during the interviews E2 has the longest experience with AM-technology, about twenty years, while all other experts have truly started their journey with AM-technology around 2014-2017. In fact, E1 and E2 have established their own AM companies during 2014-2016 while E3 has worked with AM since 2015. Then, E4´s first touch with AM technology happened through a development project in the company in 2016 while E5 and E7 wrote a Master´s thesis about the technology around 2017, and since they all have continued working with AM.

4.3 Data collection through semistructured interviews

The study is conducted as a qualitative phenomenon-based study and it is executed as a part of Turku University´s and more specifically Centre for Collaborative Research´s (CCR) output regarding the DREAMS (Database for Radically Enhancing Additive Manufacturing and Standardization) project funded by Business Finland and participating companies of the DREAMS consortium. The DREAMS project´s aim is to create an open material database to facilitate the usage of 3D printing of metals and to compensate for the lack of industry standards by the year 2024 (Dimecc 2022). CCR´s aim is to provide a handbook of best practices for implementing AM transformations. In this research data is collected through semi-structured interviews and analyzed via thematic approach. Data was collected mostly during January 2023 through seven virtual semistructured interviews of experts in the field of Finnish additive manufacturing. One of the interviews was held at the beginning of February. Each interview was held in Finnish through Zoom and lasted approximately an hour.

Knowledge of AM and its implementation has been gathered first through studying thematic literature and then via semistructured interviews with expertise in AM implementation was aimed to achieve. According to Barlow (2009), semistructured interviews are mostly used when researchers have some kind of awareness of the subject matter but would like to widen their comprehension of it. More accurately, the semistructured interview was chosen as a data collection method because of its flexibility; It may contain a mix of more and less structured questions that can be asked in varying order and words. A semistructured interview makes it possible to follow listed questions or themes but also to respond to the emerging situation at hand and being able to avoid preventing topics from arising during the conversation. (Merriam & Tisdell 2016, 109–110.)

Because the knowledge of the phenomenon was increased through continuous studying of literature together with executed interviews and because selected semistructured interview style permitted, questions regarding the theme of collaboration were emphasized by the author during the interviews, e.g., by asking separately about internal and external collaboration. In addition, for the last two interviews, E2´s and E6´s, the FAME was highlighted in the context of external collaboration. However, the ecosystem was referred to almost in every interview before these last two without asking about it separately.

As stated before, the nature of this thesis is abductive which also can be seen in the preparation of interview questions. Questions are created first based on the findings from the literature but also supplemented during the widening knowledge of the subject through interviews and ongoing development of the theory part. Interview themes have remained the same but especially the collaboration aspect has expanded to include the ecosystem thinking more specifically as described above. Interview themes on a large scale include implementation in general, challenges, people, knowledge, and collaboration. Semistructured interview questions are listed in the Appendix 2.

All interviewed experts were approached first via email in December 2022 and a few contacts were made via phone in January 2023. For each expert, themes of upcoming interviews were sent beforehand. By giving themes in advance for interviewees, the aim was to guide them away from a very technological and engineering point of view to AM. Yet specific questions were not given beforehand to prevent a lack of spontaneity in answers and because the semistructured interview method allows questions to reform during the interview. Eriksson and Kovalainen (2008, 80–81) state that interviews are in fact used commonly in business research to collect information that cannot be found in published format or concerns people´s experience from their viewpoint. As stated before, a human-centric viewpoint to AM implementation has not been studied in the existing literature like the technological aspects.

4.4 Applying a thematic approach to data analysis

This thesis applies as its data analysis method thematic analysis (TA). Thematic analysis can be used to summarize the data as well as to identify, analyze, and interpret it within and across data (Clark & Braun 2017) and it can be divided into three distinct schools which are 1) coding reliability approaches, 2) reflexive approaches, and 3) codebook approaches (Braun & Clark 2021, according to Braun et al. 2019). Based on the previous division the data analysis of this thesis is closest to reflexive TA because of its strongest emphasis on qualitative data where themes are constructed and clarified through iterative phases and the researcher has a focal impact on the final outcome when results do not emerge from the vast amount of data (Terry & Hayfield 2020; Braun & Clark 2021).

However, the thematic analysis seems to be often referred to as it is without the special division.

Ozuem et al. (2022) argue that thematic analysis is a transparent approach which is a flexible and widely used method that focuses on identifying and characterizing ideas within the data. Simplest, it develops ideas, meaning, and understanding. As well Clark and Braun (2017) also describe TA as flexible because it does not restrict research questions, data collection methods, sample size, or meaning-generation approaches. In fact, thematic analysis allows research questions to evolve during coding and developing themes. However, while the method is widely used it has rarely been acknowledged in the same way e.g., phenomenology or grounded theory (Nowell et al. 2017; Ozuem et al. 2022).

Through TA it is possible to create codes and themes from the gathered qualitative data. The smallest unit of thematic analysis is codes which include relevant characteristics of the gathered data in line with the set research questions. (Clark & Braun 2017.) Guest et al. (2012, 50) describe a theme as a unit identified through observation of the data by the reader. More accurately Clark and Braun (2017) describe themes as consisting of codes that share the same core idea or patterns of meaning and this way provides a framework for organizing and reporting different aspects found from the gathered data. However, regarding the gathered data, reflexive TA does not rely on objectivity but values the researcher´s active engagement with the data regarding the research questions (Terry & Hayfield 2020, 430).

As stated, this thesis follows the abduction logic while having a strong emphasis on deduction during the creation of the theoretical part of the thesis as well as when forming the research questions. Thematic analysis can be seen as a suitable data analyzing method for the thesis first because it allows reshaping the research questions and secondly, according to Clark and Braun (2017), it can be used for data-driven and theory-driven analysis. Also, in their previous paper Braun and Clark (2006) highlight that the choice between an inductive or deductive approach influence on how and why the data is coded. Hence even though the analysis of the gathered data aims to follow inductive logic, it must be acknowledged that strong emphasis on deduction and doing background research before data analysis have exposed the analysis as Morse and Mitcham (2002) describe it, for conceptional tunnel vision which means e.g., assigning more data than necessary to one category or seeing everything being related to each other or considering most things as examples of the subject in hand. Guest et al. (2012, 38) continue that it might also lead to the unnecessary exclusion of important findings while analyzing the data. However, Braun and Clark (2006) discovered there are also researchers who support engaging with the literature to enhance more sensitizing analysis to find delicate data features.

In addition to the thematic analysis risks mentioned above, issues of validity and effectivity must not be ignored (Ozuem et al. 2022). Quantified qualitative data might not ensure the in-depth analysis but it does not mean that analysis would be effective as it is. However, Braun and Clark (2006) point out that TA has the potential to provide detailed and rich data, albeit complex. Ideally, the thematic analysis should perhaps have an inductive approach but mostly because made decisions earlier when writing this thesis and starting from the theory, pure inductive logic cannot be executed during the analysis. What is written in the theory when starting this thesis, has molded the research and semistructured interview questions and this deductive approach´s influence in the analysis cannot be dismissed. Even though there is an aim for induction when doing the thematic analysis, it must be noted the analysis is in fact abductive. This also causes a challenge to provide an in-depth description of the data (Braun & Clark 2006). However, Ozuem et al. (2022) discovered that TA is based on phenomenology which is usually inductive or abductive.

As thematic analysis focuses on identifying and interpreting features within the data, not quantifying words or phrases (Ozuem et al. 2022), this has been the guiding principle when using the Nvivo program to form codes and themes from the gathered data. Nvivo program has been used simply; each interview´s transcriptions have been first downloaded to the program which is followed by a manual coding of each transcription. First, wanted codenames have been added to the program, and then through within analysis interesting features, paragraphs, or sentences of each interview have been dragged above a wanted code. This way the program creates a new file for each code which eases the following writing and theme creation process when all features representing one aspect are in the same place, like a cluster. Deciding not to use Nvivo to create quantified data it is aimed to avoid a problem Ozuem et al. (2022) highlight; quantified qualitative data might not effectively carry out in-depth analysis. However, there are also papers encouraging to quantifying the data and combining qualitative and quantitative data to add more validity (see e.g., Boyatzis 1998; Guest et al. 2012).

Results of the reflexive TA presented in the next chapter have been conducted first with a semantic approach where the gathered data is first organized and then chapter 6 aims to summarize and interpret the analyzed data by theorizing found patterns and characters as well as their broader meanings. As Braun and Clarke (2006) describe thematic analysis is all about seeking crosswise the gathered data to discover repeated patterns of meanings and this is also the first step of the analysis. They have created a step-by-step guideline including six phases to conduct TA. Multiple (e.g. Jones et al. 2011; Nowell et al. 2017; Humble & Mozelius 2022; Ozuem et al. 2022) papers have cited and used this particular framework which is why this original source is used here as a guideline to conduct the thematic analysis. The six phases of the TA according to Braun and Clarke (2006) are: 1) familiarizing the data, 2) creating initial codes, 3) seeking and 4) reweaving the themes, 5) specifying and naming the themes, and finally 6) producing the report.

The data analysis started when all data were first gathered through interviews and transcriptions purchased. When transcriptions are made by an experienced transcriber, it supports the reliability of the data analysis (Peräkylä 1997, 325 – 326) when it is possible to return to what is exactly said during the interviews and not just relying on memory and made notes (Hammersley 2020, 374). The first step when analyzing the data was to observe each transcription individually writing down initial ideas. Then interesting characters of the data found during within analysis were compared across each transcription and then assorted into codes. After that, assorted codes were gathered as potential themes. Next through a thematic map, themes were reviewed. Via ongoing analysis of the thematic map, themes were specified and named. However, as an exception to the step-by-step guideline, the writing process started immediately after coding the gathered data, and themes as well as the thematic map were created on the go. The final themes were identified and divided into main themes, three phases of the early-stage AM implementation: opportunity recognition, knowledge acquisition, and learn-by-doing as well as into subthemes: internal champion, AM core team, collaboration, and stakeholder buy-in which will be discussed in the next chapter.

5 Findings

5.1 The three identified phases of an early-stage AM implementation

5.1.1 The idea of the iterative process

There is a resource shortage when it comes to AM implementation in Finland, and it is not limited only to financial issues or competent workforce but covers more wider challenge, lack of AM knowledge in organizations. According to each interview, knowledge is indeed one of the most important resources an organization must acquire to implement AM successfully. Lack of knowledge in AM implementation is a complex challenge that depending on the vision and AM strategy may extend to every stakeholder inside and outside the company, throughout the value and supply chains. Based on the takeaways from the analysis, the implementation process of AM can be divided into two stages; an early-stage implementation creates the base for the later-stage implementation. The thesis concentrates on the early-stage implementation which is divided into three phases: opportunity recognition, knowledge acquisition, and learn-by-doing. To succeed in the implementation, an internal champion and collaboration with different stakeholders inside and outside the company to gain knowledge are needed alongside management´s support throughout the process.

Out of the three phases opportunity recognition is about picturing the reasons why and possible approaches to how an organization can move towards the AM technology. Whatever the initiator to start to pay attention to AM technology is or whether the execution starts from bottom-up or top-down, four things can be seen as essential for the successful implementation process: an internal champion, knowledge, collaboration, and management´s support which all are also great challenges of the implementation. Even though the opportunity recognition phase concentrates here, especially on igniting the AM process in a company, it is needed throughout the AM journey. The managerial level together with internal champions must find the right tools and paths to develop and succeed in a way that is suitable for the company and its needs because when it comes to AM, everything depends on, and opportunities must be recognized in a continuously changing and developing field.

After the spark towards the idea of AM has been ignited through the opportunity recognition phase, knowledge acquisition must be conducted either inside or outside the company. In both cases after the basic knowledge and understatement have been gathered the early-stage implementation moves from the knowledge acquisition phase to the learn-by-doing phase. However, these two phases are strongly connected, the difference is in the way the knowledge has been gathered. Knowledge acquisition points to gathering basic information about AM e.g., what can be done with different AM technologies, what materials there are, and which are suitable for the organization's purposes, what kind of know-how AM requires, and how much it costs. It can be done by a motivated person or management can start e.g., a development project concerning AM technology. Basic information can be acquired also through consulting AM service providers.

Finally, the learn-by-doing phase is usually making pilots with the help of an AM service provider and learning about the technology on the go. Some organizations have used a year or even two for information sourcing, doing analysis, and testing and usually, these organizations end up using AM either by using AM service providers or purchasing their own printers. Based on made data analysis and its takeaways, deciding whether to purchase an own printer or printed parts from AM service providers could be seen as a transition from the early-stage implementation to later-stage implementation. When an early-stage implementation is done well it creates a base for success during the later-stage implementation. It is also important to note that everything presented in this chapter is not strictly tied to one phase or even to early-stage implementation but is desirable to pay attention to multiple aspects already in the early-stage phase even if those things would be realized during the later-stage implementation. This also demonstrates the complexity and dependency viewpoint of AM.

An internal champion can be seen as the part of the implementation process that connects all early-stage phases, opportunity recognition, knowledge acquisition, and learn-by-doing together. Hence, management´s support through resource allocation gives the needed authorization for an internal champion to initiate the early-stage implementation process and an opportunity to create the base for the successful implementation of AM. While each interview offers a different kind of view towards the implementation process, a mutual understanding of the complexity of the process is certain; everything depends on something e.g., the industry, the organization´s size, and the level of hierarchy in the organization. Figure 2 illustrates that an early-stage implementation of AM technology is a dynamic process where all three recognized phases are in continuous iteration, connected to each other by management´s support, internal champion, and collaboration and all together resulting accumulation of knowledge.

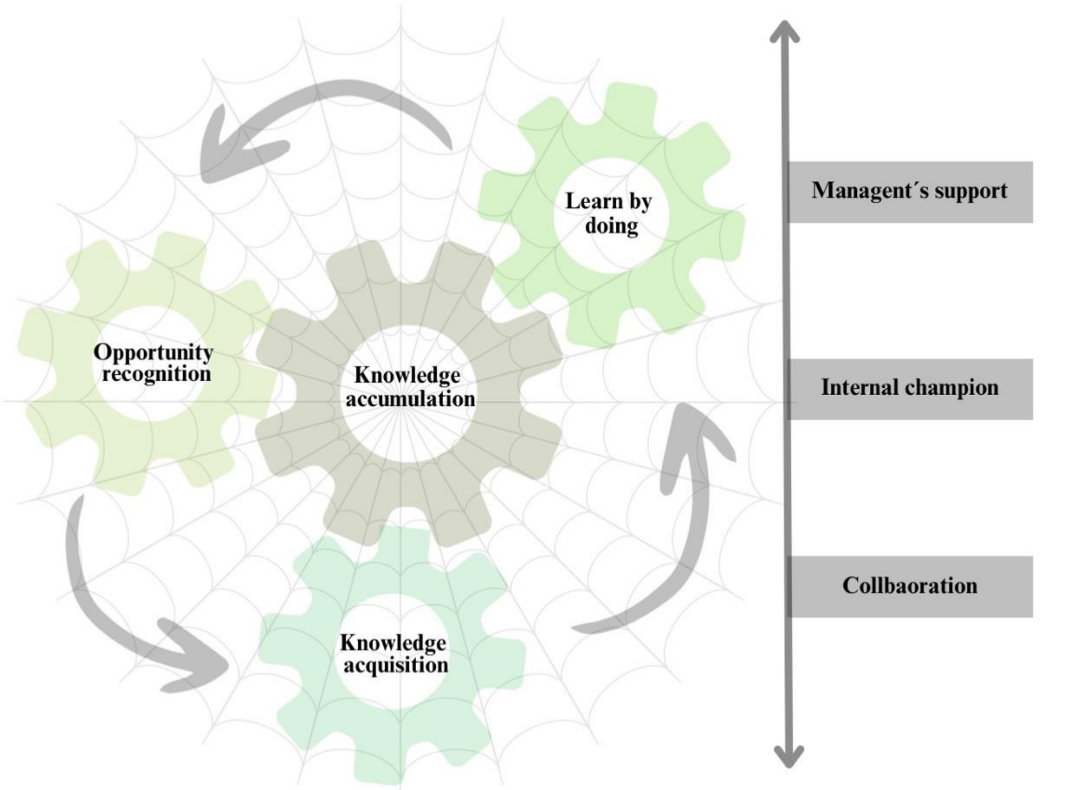


Figure 2 An early-stage implementation process of AM technology

According to each interview, AM implementation is a long process that depends on multiple factors. For instance, each interviewed AM user company has different implementation processes as well as different organizational structures, established processes, and needs towards AM and they all operate in a different kind of industry and have different numbers of resources to use and approaches to the implementation itself. In addition, E5´s organization has its own 3D printer while E6´s and E7´s organizations use AM service providers to print the needed parts. Also, each of the represented AM user companies is at a different level in the implementation: E5´s organization could be seen in a later stage or already done with the implementation itself while E6´s organization uses at this point AM technology to mostly make prototypes and E7´s organization aims for systemic change. It must be highlighted that all the represented user companies started their journey around 2017 but because of the differences touched on above, their processes are in very different stages. Next, each of the recognized early-stage implementation phases will be described more deeply. Even though they are represented in a certain order, the question is about a complex iterative process where the setup can vary and go back and forth time after time.

5.1.2 Opportunity recognition

There are multiple ways how an organization can start to pay attention to AM technology but what is in common in all these different ways is some kind of initiator. For example, whereas E1 outlines media as an initiator of interest, E2 names a need to make production more effective, E4 describes a situation where a competitor has started to utilize AM technology, and E5 a need to replace old technology with a new one. Hence, the first touch to AM technology might also come from AM companies themselves through marketing or merchandising. Even though the initiator may vary between organizations, the execution of the implementation process of AM can start either bottom-up or top-down. Few have mentioned how it could help in the challenges of internal communication and knowledge sharing if the decision to move towards AM would come from the upper levels. According to E2´s experience, the decision to move towards AM comes fifty-fifty from bottom-up and top-down:

> In product development and design, there comes half of the observations that we need a different solution for something. So, the design side says, let's see how 3D printing fits into this. Then there's the other half, where are the decision-makers. -- E2

Especially E3, E4, and E7 describe how the implementation process may start from the bottom, the employee level of the organization. But also here, first a single employee must have had an idea of AM technology somewhere, it can come e.g., through education or own personal interest or those initiations mentioned above. On the other hand, particularly E5 and E6 describe a situation where the top management of the organization acts as an executor of the AM implementation process. Nevertheless, the executor of the process can also be something in between these two opposites; middle management can recognize employees with a strong interest in AM technology and bring together these similar minds. In the case described by E4, the middle manager had also first paid attention to AM technology through a project. Based on these views, the term AM technology must come up from some reason or circumstances for the superior, then he or she can bring together similar minds and most importantly allocate resources to get them started:

> -- We gave two people interested in 3D printing a task to spend a couple of weeks and analyze what's happening in the 3D printing market and what a company should do if they want to join this game. They did such a good job that when we saw the report, we realized that this is something we need to present to the entire management of our company -- E4

Yet there are different ways the early-stage implementation process may be ignited as described above, the first challenge in opportunity recognition or the whole early-stage implementation itself is quite abstract: to start the implementation process the initiator must emerge or come across with the term additive manufacturing. However, the solution for this first challenge from the top management point of view like E2 names is mostly based on coincidence. AM technology is raised in many reports and megatrends as well as on display in different exhibitions which makes it likely to management to clash with it. When the initiative comes from the top-down, management should find an eager employee from the company or recruit one to start the AM implementation process. In the other approach, an employee motivated by AM raises the subject for further discussion. However, in both cases management´s approval to continue into the knowledge acquisition phase and allocation of time and human resources are essential.

5.1.3 Knowledge acquisition

Knowledge acquisition is an important part of the AM implementation process. If it is not done properly or well enough like E1 and E2 describe or according to E7 perhaps not at all, the idea of implementing or using AM is at risk. Experts representing AM service providers describe that usually when the idea of AM technology occurs in the company next step is to contact a service provider. However, based on the interviews these contacts can be divided into two groups: companies who already are familiar with the AM technology and those who want to know about it. Consequently, this division leads to two possibilities or questions to answer when the idea of AM technology has reached the company, whether to acquire the knowledge inside or outside the company. When thinking about the AM service provider's role in the early-stage implementation, there are most likely two options for why an organization approaches a service provider, either it wants more information about AM for example through training or consulting or it wants to do a pilot using AM technology in the learn-by-doing phase which will be discussed in the coming section.

One challenge connecting to knowledge is continuous development; AM technology has evolved over time. If this development is not recognized especially in organizations that have once tried the technology and dropped it because of its unsuitable features back then, they might not see the possibilities AM could offer today. When gathering AM competence, it is vital to become aware of the limitations, possibilities, and future prospects of the technology. Especially when combining development with financial aspects, it is hard for organizations to see the bigger picture and whole life costs of 3D printed products. According to E4, product prices might triple when using AM but in a few years through continuous development of the technology, prices could be exactly the same when compared to the original price but also products are 50% lighter than the original products. Through proper knowledge acquisition together with collaboration and information sharing with different stakeholder groups, it might be easier to sell the idea of AM implementation to the upper level in the organization as well as to the external and internal customers:

> The management talks about numbers that need to be monitored and observed. For the past four years, we have been tracking the direct cost savings of our tool production. It's a simple thing that, makes visible what we are doing. If we don't make it visible ourselves, no one else will. They'll just say, 'Well, we checked the system, and you spent 10,000 euros on materials,' and then I can show, 'Yes, and we saved 200,000 with those.' You always have to be able to prove it with numbers. E7

In addition to the challenge of measurable life cycle cost an important part of the whole knowledge accumulation is to keep an accurate and real-time record for example how much time some 3D printed part takes to design and print and then show how much time it would take with the traditional methods. Besides knowing the numbers, qualitative as well as practical knowledge is needed when mapping out machine manufacturers, designing 3D printed products, operating the machine, and processing the final products. However, it is also notable that every material and machine requires its own knowledge. One can learn in school to use one kind of AM technology but in real life, an employee possessing one kind of operation experience with one kind of AM machine usually must be trained to use the exact machine and materials in the company:

> The machine manufacturers' training is very good, and that's probably where the most specific expertise comes from, understanding how to use that particular machine. Universities and others might be more focused on providing general knowledge. -- We also get asked about training sessions. E1

Anyway, several interviews indicate that AM requires complex know-how. If there is not enough knowledge in the organization about AM, it easily leads to false conclusions about the technology's suitability for the company. For example, according to E4, there are about thirty different technologies that all are under metal 3D printing. The first step to acquiring AM knowledge is to understand the definition of the term additive manufacturing to avoid a chance of misinterpretation. E7 clarifies that educating people about AM in the company is a challenge because e.g., after two-hour training employees think they know what AM is, while really the minimum level of knowledge requires two weeks of training. This also demonstrates well why knowledge acquisition is a challenge, good AM examination takes time, and similarly so does training the basics. For example, E1 demonstrates well how delicately the knowledge acquisition might fail if it is not done properly or at all:

> A designer had sent a part to be printed using technique X and material Y. -- When the customer received printed parts, they noted that these surface qualities didn't suit us, this material didn't work for us either, and this product wasn't good enough. From that, the conclusion was drawn that the AM technique wasn't good, which was completely wrong. The correct conclusion should have been that one specific technique doesn't suit their needs. E1

While AM implementation demands complex knowledge in multiple areas, E2 describes how AM and its implementation also require a huge amount of curiosity and how there is a demand for creativity. These can be seen as useful skills throughout the implementation process, and they will be discussed later. However, skillset and organizational culture are aspects that need to bear in mind when acquiring knowledge about AM´s requirements to build e.g., AM strategy or figuring out if the organization actually has what it takes to implement AM or what needs to be changed.

It could be assumed that creativity and an ability to think outside of the box are skills that especially E5 needs as an only internal champion of their company and when the organization is not part of the ecosystem; E5 seeks information from sources that are not mentioned by those who are members of the FAME ecosystem, like machine´s maintenance person and importer. In addition to different sources of information, few of the interviewees added machine manufacturers as information sources when it comes to 3D printers. In fact, E1 characterizes the machine manufacturer's instructions as excellent for gaining competence to use the exact printer. However, E5 described that the training they received had some rough edges while E6 defined it as accurate and competent.

Nevertheless, no matter what the source of information is, one thing is sure; AM technology requires wide knowhow which cannot be obtained without collaboration:

> No one can manage everything related to 3D on their own, so that's why as a company, we have a lot of partners with whom we develop together, share ideas, and so on. E4

As stated during the interviews, organizations seek solutions to challenges too narrowly meaning they need to widen their horizon and be curious. Also, if a broader group had knowledge about AM in the organization, there could be more different solutions for challenges than one person alone might find. For example, E5 is the only one who has the competence in the organization to use AM and notes that know-how accumulation for one person is sometimes a challenge. The challenge of narrow-mindedness can be won through sharing the knowledge inside the company and by building an AM core team but also by contacting an AM service provider or other external sources. Based on the interviews, a usual answer to finding wider solutions or simply helping the implementation process itself is contacting an AM service provider. Collaboration and AM core team aspects will be described in more in-depth after the next learn-by-doing phase.

5.1.4 Learn-by-doing

In this learn-by-doing phase, the main emphasis is on making a pilot through AM technology. Perhaps, one of the biggest challenges when learning by doing is a corporate culture which was highlighted especially by E2, E4, and E7. For example, one of them states that successful implementation of AM technology requires “a safe place to test and fail”. This kind of culture is in fact one possible solution to the challenge of narrow-mindedness but to the successful implementation as well. However, connecting to narrow-mindedness and corporate culture, established processes, and hierarchy in an organization could be named as a challenge of stakeholder buy-in. Below, E7 describes well how in fact the whole implementation process is about humans and their feelings which bring their own challenges for the implementation process:

> Emotions play a significant role because if someone does not understand how important or fantastic it (AM) is, there's a strong temptation to give up or say, 'Screw it, I'm out.' -- Luckily, we have been able to convince people. It doesn't work by just saying, Look, even airplanes are 3D printed. We don't make airplanes, so what? You always have to get inside the internal customer's

> mind to figure out how we can convince them. You might have to create this and that test -- even though we already know it works. E7

The challenge of stakeholder buy-in emphasizes both phases of an early-stage implementation; knowledge acquisition and learn-by-doing. Like each of the experts noticed at least at some level, making a pilot is an essential part of the implementation process, and according to particularly E5´s and E7´s own experience pilot can in fact determine whether to proceed with the early-stage implementation and continue it to the later-stage implementation. For instance, E5 describes how in their company pilots were made in a few different AM service organizations after the knowledge acquisition, and based on the successful pilots, they decided to purchase their own printer. As the majority of interviewees underline, pilots are an important part of AM´s internal marketing and spreading of knowledge to the different stakeholders inside the organization. Especially E7 describes that the closer the printed part is to its stakeholder´s agenda the more there are employees who believe in AM through the concrete pilot and the more there are internal champions marketing the idea of AM to different departments and wider groups of people. This also adds one more competence requirement for the AM champion´s toolkit, the ability to sell, which will be discussed later. Next E4 continues well with the former citation of E7 by describing that the personal will and interest of an employee are one of the key ingredients when it comes to successful implementation:

> It all starts with having that personal desire and interest. -- And, of course, it needs to be somehow linked to the work you do. If you're a software developer working on cloud applications, 3D printing might not interest you much. But then again, we have colleagues in our company who are coders, and yet they have 3D printers at home. So, interest, that's the key thing there. E4

The challenge of stakeholder buy-in connects also to the training of employees. According to E4, it is not effective to train every worker in the organization about AM technology if the idea of 3D printing is not part of all employee’s everyday work. But if there is even a small chance that an employee could find a place to utilize 3D printing, it is worth it. Nevertheless, creating trust towards AM technology in stakeholders demands successful pilots close their own operations or even from their own parts, and trust in the technology is in fact the key to the will to learn more about AM. Even though the experiment is a good way to gain ground for AM technology in the company, E7 noted that after justifying AM and answering the question of why to use it the next step is to answer how. S/he highlighted that without employees´ motivation, the question of how cannot be implemented, nor knowledge spread any further which returns the implementation challenge back to people. However, E5 makes an important point regarding the whole process of implementation, what kind of changes are needed at the organizational level, and to what extent learning should be organized:

> -- Of course, it depends on how AM is implemented. In our case, we don't reorganize the entire company around AM, the change is quite minimal. It's more of a physical change, like having dedicated spaces, and figuring out what it needs. -- It smoothly started rolling once we got the parameters right, and there wasn't much to think about. We just started doing it. E5

As stated before, whereas knowledge acquisition and learn-by-doing phases are strongly connected, through well-done knowledge acquisition there should be an understanding that gathering information through testing only one technique of AM is the wrong way. For instance, E1 and E4 noted that lack of knowledge drives to wrong conclusions, and E7 highlighted that one failure might lead to rejecting AM technology for good which makes the whole early-stage AM implementation fragile if the importance of knowledge is not widely recognized. Mostly because the implementation is already vulnerable as a process, it will be more sensitive and at stake if organizational hierarchies and established processes alongside the actual slowness of the change are not at least considered during the implementation which originates from the lack of knowledge:

> We have spent two years validating our first series production component so that we can demonstrate that we were right two years ago. -- The timeline is long—it's not quick and easy precisely because we don't yet have that organizational trust. Let's say, on a very small scale, especially with tools, the risk is very low. But at the same time, when we're dealing with critical parts, that's when the risk increases. Then, we can't afford it to fail, so we have to sacrifice speed and follow the old ways or processes precisely. E7

Also, as stated in the citation above, one important reminder is that pilots should be printed first from components which failure is not that crucial. Related to this, one interesting aspect that only E7 raises during the interviews is that in Finland everything needs to work before it can be accepted. Therefore, AM implementation can be characterized as a slow process that demands motivation, trust, and time to be successful. Also, a cultural understanding of the way things work especially in the international company or AM core team would be advisable. Especially to the challenge of creating trust, E7 offered an answer to give internal champions the possibility to work full-time, or at least half the time, with the AM implementation because one crucial character towards a successful implementation is to keep things going forward all the time which indicates that stopping the process for a certain amount of time may be disastrous for the success. Also, E2 highlighted that only having financial resources to implement AM is not enough, people and their time are needed.

In addition to the previous, E3 brought forward a virtuous circle emerging from the first printed part or case. Also, E7 noted that if it is possible to convince people by showing a successful printed part that has a positive impact on job descriptions, the attitude towards AM slowly starts to turn in a positive direction. Through positive cases and suitable 3D printed parts employees or teams who were not familiar with the technology before, are most likely ready to commit and learn about 3D printing as well as to allocate finance. However, it must be mentioned that building trust takes time, even years. Cases that have been produced by following the old protocols are key factors when creating a trust to use AM technology and through examples knowledge spreads.

To sum up the three described phases, opportunity recognition in the early-stage implementation is about getting the implementation started usually either bottom-up or top-down. Especially knowledge acquisition and learn-by-doing phases possess a lot of common features and their boundary is not always clear, especially when it comes to division into early-stage and later-stage implementation. However, as stated earlier knowledge acquisition needs to cover multiple aspects so the decision to move towards later-stage implementation can be made. Organisations should conceptualize the wider picture of AM to understand to complexity of the technology. As pictured in this chapter knowledge is gathered through both phases and spreading the knowledge can happen through internal champion or champions who create the AM core team. Also, internal stakeholders as well as external and internal collaboration have an important role during the early-stage implementation. Next, these building blocks of the early-stage implementation will be introduced in more in-depth. Like the three phases, the building blocks are connected to each other and suitably for the complex nature of AM, hard to keep apart.

5.2 Interactive building blocks of the identified three phases

5.2.1 External collaboration, enabler of prospects through co-innovation

In each interview, the importance of collaboration was highlighted at least at some level when interviewees emphasized the meaning of external collaboration. This is interesting because only one of the companies, the company which E5 represented is not part of the FAME ecosystem. All the others named exactly FAME ecosystem as an important factor of the industry. It offers multiple benefits for its member organizations when it comes to for example collaboration, challenges, and know-how. Ecosystem brings together companies and their knowledge:

> -- There's a lot of information coming from the ecosystem. Methods, how they've evolved, information from exhibitions about what's happening, and then, from other companies, what they have done, what kind of case studies they have. Collaborations. Various meetings or other events, and exchanges of information with individual companies with similar interests, have come through FAME. E6

In addition to FAME, E3 and E7 operate in one more AM ecosystem which operates in Finland and Sweden. Nevertheless, in this analysis the FAME ecosystem can be discovered more interesting because of its Finnish heritage, and E3´s and E7´s interviews concentrate more on the FAME ecosystem than the other one. However, E2 describes how external collaboration is not always limited to the ecosystem and AM expertise but goes beyond industries, e.g., the wood industry, architecture, and professions such as designers and artists as well as educational institutions like universities of applied sciences. For example, E5´s organization does not belong to the FAME ecosystem, but the interviewee describes how upcoming challenges usually can be solved by communicating with the local university or AM machine´s maintenance person. This demonstrates well how the collaboration is mostly based on interpersonal relationships between AM experts and how the collaboration and information sharing goes beyond organizational barriers:

> -- We aim for these bilateral connections, not only between companies but also between individuals, so that we can move away from the jargon and coffee-drinking clubs, making it efficient. Similarly, when our external designer becomes internal, I talk to them in the same way, sharing the same goals and challenging issues. -- This is not a traditional way of operating. E7

Knowledge as a theme will be discovered more widely in the next sections but in addition and clarification to the previous, E5 also acquires information from the printer´s importer and in the last resort from the manufacturer which in this case is located in German. Other interviewees bring forward that information is usually gained through the ecosystem or AM companies like E1, E2, E3, and E4. AM core team will be described later but it is important to clarify that the core team usually consists of internal AM champions even though the team itself might be distributed. Collaboration and communication can work also despite demographical and national barriers:

> We have a very international team. Last summer, we had an intern from Iran, and this year we have a graduate student from India. My boss is Italian, working remotely from Italy. Our expert in Vaasa is Italian. -- I'm currently sitting in Helsinki, our factory and all other colleagues are in Vaasa, some are working from abroad, and yet this setup still works. E7

Like above E7´s citation as well as E3 describe how AM can employ summer trainees and Master´s thesis students. E7 names this action as social responsibility which serves the needs of the AM industry. Through operating a few months in the organization students or summer trainees have gained knowledge which they take with them after the employment ends and hopefully continue working among AM, develop it for their part and this way drive forward the whole AM industry. This points out that through sharing knowledge and pursuing the common good, also external collaboration is essential among AM. Because the common message of interviews was that no one succeeds alone in AM industry, especially in Finland, it feels necessary to note that according to E2, new businesses arise from co-creation. E2 presents an idea about AM´s future worth for organizations: they should use AM to forecast their future operations and products through curiosity and sharing ideas. E5´s and E6´s interviews support this idea of foreseeing and even reshaping the company´s services through AM technology. E6 presents an idea of a digital warehouse for spare parts and E5 an idea about establishing spare parts service through AM technology.

It is worth mentioning that E1, E2, and E3 represented companies that have been born to respond to the AM resource shortage in Finland. Each interview revealed that there is a need for new operators in the field. Also, the uneven geographical distribution of AM services was mentioned by E5. Related to Northern Finland´s lack of AM operators, E5 hesitated that the company could start to offer AM services in addition to their production in the future. However, it was also mentioned during the interview that 3D-printed parts can be easily ordered from AM companies regardless of their location. Even though there are two ecosystems and other forms of collaboration mentioned during the interviews, E2 highlighted that the FAME ecosystem is in fact unique. The need for collaboration via FAME connects to the complex nature of AM technology and resource shortage, especially AM knowhow and the number of 3D printers in Finland:

> No single provider can offer all the requested materials or delivery amounts. That's why most of the players collaborate e.g., if the machines go down, we have the ecosystem to ensure that we can always deliver to the customers. It's like a resilience thing. It doesn't work like this abroad, it's quite a Finnish phenomenon. We are competitors, but at the same time, partners. It's maybe one of those ecosystem things. E2

Regarding working alone and resource shortage, one challenge is sometimes access to information and occasionally simply lack of information. For example, E4 describes that the company has bought access to some material databanks and describes the lack of comprehensive material databases as a bottleneck. The lack of information about materials has launched a common need among AM-using companies to collaborate and create a database whose determined purpose is to advance additive manufacturing in Finland. It is also noted that collaboration enables more extensive research through sharing financial resources which perhaps boosts information sharing. Even though resource shortage overshadows the development of the AM industry in multiple ways presented in this section, unrivaled collaboration through the FAME ecosystem as well as via other operators in the field is a possibility for a small country like Finland. In addition, through an ecosystem company does not have to struggle alone but can be a part of a bigger system. While external collaboration can be seen as essentiality already at the beginning of the implementation process being an important source of knowledge, its significance only emphasizes while the implementation process proceeds. However, internal collaboration shall not be diminished.

5.2.2 AM champion, a fostering power of internal stakeholder buy-in

The AM champion can be described as a person who drives the AM implementation forward and is a key person in a successful implementation process. However, implementing AM requires collaboration, and usually AM core team unfolds. The idea of an eager or strongly motivated employee about AM came up particularly from the interviews of E3, E4, and E7. In fact, E4 and E7 named this eager person as an internal champion. Consequently, the internal champion was described usually as a young person, who perhaps has a few years of working experience or comes to the organization to do a Master´s thesis, but mostly as a person with multiple skill sets. Even though the idea of an internal champion was not that strong in every interview, each expert named skills or characteristics needed in an organization for a successful implementation such as dedication, eagerness, imaginativeness, curiosity as well as the ability to cooperate, foresee, sell, and market. It is worth highlighting that especially E2 brought up the need for creative and inventive minds and management's ability to foresee the future path of the organization as characters or abilities needed when pursuing a successful AM implementation. In addition, both E3 and E7 compare spreading the AM knowledge to selling which indicates that succeeding in AM implementation requires multiple skill sets including technological knowledge as well as good people skills.

Nevertheless, when the implementation starts from top-down the challenge of finding a multiskilled employee interested in AM can be answered mostly through successful recruitment if there is no internal AM champion to be found. Still, recruitment can be quite problematic if the aim is to have an AM expert in the organization due to a lack of a competent workforce. The shortage of AM know-how is described in the next section. Nonetheless, sometimes students interested in AM may work as an initiator of the process by making an AM report as their final project. If the AM report is done well and the opportunity is recognized, the student might become an internal champion who drives the implementation process forward in the organization. It is also noted, that through poor knowledge acquisition, an organization might abandon the idea of AM. Based on these views it can be stated that hiring a master´s thesis student or an employee to do the first knowledge acquisition can be either an opportunity or a risk:

> -- They've been lucky and done a good recruitment if things have progressed positively. So, you really need some kind of internal passion, enthusiasm, and sales skills to get a 3D printing project moving forward within the company. I also know cases where one has hired a Master´s thesis student to make a report on 3D printing and then the matter hasn't progressed at all. E4

While external collaboration is identified as a possibility among each interviewee, internal collaboration is mostly a challenge. Exceptionally, in E5´s represented organization internal collaboration is not seen as an issue; every employee in the organization is aware of AM albeit does not know how to use it. Still, for a long, there has been only one person, an AM champion, who has the needed expertise to sovereignly operate with the 3D printer. This perhaps strengthens the view of people being one of the barriers to AM implementation and demonstrates the need for motivated persons to learn about AM and use it in daily operations. However, below E2 describes well the situation arising from interviews of AM user companies' experts E6 and E7:

> Let´s picture a company with over a hundred employees and there are teams. In one team, there might be one or a few persons who know about 3D, and

> they might be using 3D printing quite proficiently. Typically, the rest of the organization is completely clueless about the work they're doing with AM. So, the obstacle is that the information doesn't spread within the organization about 3D. E2

In the above citation, the need for collaboration and discussion channels especially in larger companies arises. According to E6, the answer to the challenges of knowledge sharing and collaboration inside the company could be establishing an organization inside the company that would push AM collaboration forward which is something that in E7´s represented company has been done. However, this kind of action requires at least one AM champion to get all started and multiple to operate. Even though an AM organization inside the company might be one solution according to E6 and in addition, E4 suggests creating an AM academy inside the company, it is clear from E7´s point of view that collaboration with other departments inside the organization is still a huge challenge for implementing AM vertically and horizontally in the organization. Hence, internal collaboration in the implementing organization requires a champion or few or the AM core team who have the fuel to push the implementation process forward horizontally between different stakeholder groups and vertically even from the bottom to the managerial level:

> Once again, you need that enthusiastic person who brings together the various stakeholders within the company and has the energy to organize training sessions for those different groups. -- And it has to be sold to each group -- the one enthusiastic AM person within the company also needs to be a salesperson for the idea to move forward. E3

It is also worth mentioning that internal collaboration can have different levels. Especially E3 and E6 bring up internal collaboration between the organization´s different locations. E6 sees a challenge in communication between departments and their different locations while E3 describes collaboration between locations as quite seamless. However, there is a noteworthy difference between these two companies, E6 represents the AM user company and E3´s organization is the AM service provider. This indicates that when the subject is familiar to everyone in the organization, it does not matter if the communication and collaboration need to go even beyond the geographical locations of the company. Also, there is no need to prove the significance or possibilities of the technology, because AM service providers already have the required know-how about AM.

When it comes to internal champion, organization’s size, and AM´s purpose of use, E5´s interview offers an interesting point of view to the AM implementation mostly because s/he operates in a small-sized organization where AM is used as an auxiliary activity and E5 is the person who runs the AM activities alone. The definition of an internal champion perhaps differs between different companies with different needs, organizational structures, and sizes. For example, E5 does everything from discussing with clients to designing, printing, and processing the 3D parts while some other experts from larger companies have pictured how the designing and printing could be outsourced for AM service providers but selling the idea of AM technology as well as like educating people about AM in different departments is what they do as champions. Also, another notion about the idea of an internal champion is that not every company has an internal champion or champions who could work beyond the department barriers among AM as E7 does. For example, E6´s department has a different perspective and need towards AM technology because now they use the technology mostly for prototyping. However, some kind of cooperation and discussion channel in addition to occasional projects might be needed, especially if there is a willingness to implement AM horizontally. In fact, E6 describes how the collaboration and information sharing between departments is thrust on individuals when there is no project for AM going on:

> -- If there were an organization where everyone could discuss together, it would definitely help and make things easier. -- it would be more systematic if there were common development projects and other things, it would be more sensible and easier if it started from the top, including resources, budgets, and so on. -- For example, when we had that bigger project that started from the top, things happened, and everyone was involved. E6

However, about the previous it must be noted that the need e.g., formal discussion channels might not be as crucial in smaller companies as it can be in larger ones. Also, sometimes like in E5´s represented company´s situation, AM can be implemented and run successfully by one AM champion even though it makes the process strongly dependent on one person and this way quite vulnerable. As compared to E7´s situation, one or two AM champions are not enough, but the entire AM organization is needed to run the implementation process. Once again, the way AM is or will be implemented is the sum of multiple variables varying from the organization´s size to its AM vision and everything in between. However, if there is no eager employee to push the idea of the AM implementation from the bottom-up or the management takes no interest, it leaves the question open whether the implementation will move forward at all or be successful even if the knowledge acquisition would be done at least in some extent. Hence, some kind of entrepreneurial spirit is required to things move forward with AM. Strongly connected to the idea of an internal champion, the next section describes the AM core team consisting of multiple AM champions. Also, resource shortage especially related to AM know-how will be described in the next section.

5.2.3 AM core team and knowhow creation, no one succeeds alone

During the early-stage implementation interest towards AM hopefully unfolds inside the company and an AM core team sharing the strong interest towards AM can evolve. Usually, a core team consists of three to ten employees depending on the size of a company and the use of AM. For example, E7 represents a large-scale company in which the AM core team consists of about 10 team members, and now through education and continuous selling of AM inside the company about 50 employees know the basics of the technology while with good luck, others might know that metal can be even printed. The meaning of collaboration regarding AM inside and outside the company has been underlined in most interviews likewise the importance of a core team creation as part of the implementation process. However, only E7 brings up that the AM core team can have internal and external members.

As noted already, even though team creation is recommended it might not be the case in every AM implementation: in E5´s organization s/he has long been the only one who runs the operations and has all the knowledge about AM. There are two interesting aspects of E5´s situation. First, the person in training is quite new in the company meaning longer-served employees are not upskilled and secondly know-how is transferred by E5 to the new employee indicating perhaps a lack of AM skilled workforce in the markets. Also, the expert described how some customers have wondered how there is only one who operates everything regarding 3D printing. This demonstrates well that when one person is responsible alone for the company´s printing process it requires multiple skills which cannot exist, according to all the other interviews, without dedication to the AM. In addition, one person´s AM team makes the process vulnerable. Several interviewees have described how it would be sensible if there were at least a few internal champions who would have the knowledge and competence to use AM in the company. The next citation pictures the situation when the aim is to integrate AM throughout the company:

> --Especially in the early stage, you need to find those few who would do this even without being told. And this kind of champion thinking in different circles, at different coffee tables, there must be someone, a champion, who

> drives AM forward. -- It's a team effort; someone ignites the spark, but someone actually does the work. There are a lot of people involved. – E7

Concerning the previous, one typical challenge noted by everyone else than E5 is resources. Especially E1 states that large companies can hire an AM expert to carry out the recognized phases of the early-stage implementation, knowledge acquisition, and learn-by-doing, while small companies might not have the resources to hire a new person in the company. However, according to E1 and E3, it is hard to find an employee that already familiar with AM technology. Also, E7 identifies the lack of a skilled workforce but points out it can be a possibility when looking outside Finland.

As stated before, one way to get to know AM technology would be to contact an AM organization to ask for more information about the technology during the knowledge acquisition phase. It is also stated that AM technology itself is quite expensive which means that not everyone has the assets to purchase their own printer during the later-stage implementation nor it would be advisable in every situation. For instance, for E5´s organization, the decision to buy their printer has been quite a well-functioning solution while E6´s and E7´s represented organizations purchase parts successfully as a service. This also demonstrates that the need for AM know-how can differ quite a lot based on the way of using AM. In addition, E2 describes a situation where an organization has purchased a 3D printer but does not use it, mostly because the early-stage implementation collapsed due to inadequate knowledge acquisition, lack of resources such as time, unsuitable organizational culture, and perhaps lack of knowhow:

> So, this is a very typical story, you're diving into the action without gathering enough information beforehand. -- One company bought an expensive metal 3D printer, but then there was no culture or resources allocated within the company to activate the metal 3D printer -- in the long run because all the other activities took the attention away. -- E2

An important notion to previous is that even if there is an internal champion, the implementation might not succeed because e.g., the lack of collaboration, support, and resources. In addition, E4 amplified that even if an organization asks for help with the implementation from an AM service provider, they need to go through the process internally; they must implement learned cases and knowledge inside the organization, and e.g., organizational culture must allow doing so. While knowledge seems to be the key when implementing AM, the implementation process needs a corporate culture that supports to test and most importantly also to fail. More accurately E2, E3, and E4 encourage organizations to learn by doing, and especially E4 underlines the importance of organizational climate that allows both, trial, and error. In addition, E5 described how they learned to use AM exactly through experiments and hoped they would have had more knowledge at the beginning of AM implementation. Hence, this implies that learn-by-doing is an important part of the implementation process.

Nonetheless, E5 and E6 did not highlight the need for existing AM expertise when hiring new people or educating already current ones. Still, they both mentioned how the employee should have at least some kind of know-how for example about designing. When there is an AM core team, tasks, and skills can be divided among different people but as learned from E5´s example if there is only one, or perhaps two internal champions in the organization the skillset must be overall. Even though training might not be a challenge, the challenge is to find the right person with strong motivation to learn about AM. Also, as discussed before, AM team creation and collaboration is recommended because through a team it is possible to e.g., answer to the challenge of narrow-mindedness and tackle AM operations vulnerability which alone might be a lot harder to reply. However, technological understanding of AM in the AM core team or the AM champion´s toolkit is not always enough, imagination and even the ability to think outside the learned worldview, especially through school is needed:

> --The biggest constraint isn't a technical limitation but instead -- imagination. We're talking about things that, in terms of e.g., design are from a completely different world than everything taught in engineering education so far. So, the biggest constraints exist within people's minds. We work widely with companies on this imaginative aspect. -- E2

Because AM knowledge must usually be acquired through training old or new employees, it demonstrates well the current competent employee shortage. Anyway, E3 recognized the lack of competence in the AM industry but in contrast to other interviews described their situation a bit differently because E3`s represented organization was able to hire a skilled workforce. The experience was a bit like E7´s, they have been able to hire competent employees all over the world. Nonetheless, even if an organization can hire a competent workforce in Finland, it might transfer the issue of a lack of employees to another company. In fact, E3 states that it is a challenge to hire AM experts because once you do it, you also steal an employee from your acquaintance. This demonstrates well how little there is a skilled workforce to work among AM and how few have implemented AM and trained their employees to use the technology in Finland. In fact, according to

E1, the small number of companies using AM in Finland might be the one reason why there is not enough competent workforce. In the next chapter conclusions from the findings will be stated in relation to the literature part of this thesis.

6 Conclusions

6.1 Knowledge accumulation, the core of AM implementation

As brought up in the introduction by e.g., Priyadarshini et al. (2022) and observed during the analysis, the framework for AM implementation is quite a challenge to create because of e.g., the complexity and lack of best practices of AM implementation. On the other hand, it seems that the knowledge is there in the field of AM industry and behind the experts operating with AM, but it is not researched as the technical aspects of AM technology have been. However, it must be stated that the frameworks presented in the literature, have surprisingly a lot in common with the identified and created early-stage implementation framework (see Mellor et al. 2014; Gehre et al. 2016; Deloitte 2019; Butt 2020; Kamara & Faggiani 2021) and they all can be seen complementing each other. As stated, the form of AM implementation seems to depend on multiple aspects (Deloitte 2019; Kamara & Faggiani 2021, 154, 158), e.g., the organization´s size, industry, culture, need, AM vision, and strategy which makes it quite challenging to create an accurate and detailed framework to guide an organization or managerial level through the AM implementation. Regardless, the thesis aimed to shed light on this complex process, and as a result, an early-stage implementation framework presented in the previous chapter was created. The identified framework turned out to illustrate the cornerstones of a successful AM implementation process which core is building around knowledge accumulation.

Also, Kamara and Faggiani (2021) recognize the importance of knowledge, however, this thesis emphasizes it: knowledge can be seen as the holy grail towards successful implementation, and lack of it can paralyze the whole process, it is the challenge and enabler simultaneously. Martinez (2019) has identified how an organization´s digitalization paths are individual but can share complementary and comparable elements, like the three identified phases of the early-stage implementation and knowledge as a common denominator of the phases. First, the opportunity recognition phase ignites the process, then through knowledge acquisition, basic information about AM is gathered, and finally through learning by doing practical know-how can be acquired. However, these three phases are in continuous iteration. Knowledge accumulation through the identified three phases is the key to deciding whether to move forward by either using AM service providers or purchasing their own printer. It also determines whether the organization has what it takes to succeed in the implementation. However, in the end, the success of AM implementation lies in understanding the complex entity and how little organizations know about AM at least in the beginning. Falling into the hype of AM or behind in development can be fateful for an organization.

Especially in Finland where there is a shortage of AM experts, engagement of the key employees, AM champions, is essential to keep things going forward. Management can support the implementation process e.g., by allocating time by creating full-time employment among AM technology and the AM strategy should be created to have objectives to move forward. However, even though the foundation to move forward with the implementation is favorable when the knowledge has been gathered, it does not exclude upcoming challenges related to e.g., supply and value chain or questions about serial production during the later-stage implementation. Also, the validation of AM must continue, and some might even think about breaking new ground through AM. Even though managerial support through resource allocation is highlighted multiple times, the support is also needed the other way around, AM champions must help the management understand the needed actions as well as the challenges and possibilities of the technology to gain the needed resources. Knowledge accumulation is needed on both sides.

6.2 People, demand for intuitive understanding of AM

Properly executed early-stage implementation prepares an organization to move towards later-stage successfully, e.g., serial production and system-level integration, however, it does not mean that in the later stage, the process could not go wrong. For example, Attaran (2017) warns, that if production time does not increase it might lead to taking serial production to traditional manufacturing methods. Still, the accumulation of knowledge, qualitative and quantitative, is an asset when deciding to move forward with the implementation process. Attaran´s (2017) observation implies the challenge of measuring and transferring AM knowledge to the managerial level. Like few of the experts stated, management speaks numbers but through measures, at least in a short time all AM benefits cannot be verified. This is why intuitive knowledge in management is essential and knowledge accumulation during the early-stage implementation is fundamental. This also reflects the question of whether the metrics used in today´s organizations are accurate to answer requirements of today´s business world, e.g., responsible business or potentially disruptive technologies.

One interesting viewpoint that also supports the claim of AM being studied mostly from the technical aspects (see e.g., Caputo et al. 2016; Kamara & Faggiani 2021, 3; Manesg et al. 2021) and on the other hand still rather a low degree of utilization of AM in Finland is that in the theory, listed benefits of AM focus mainly on the technological characteristics. Mostly, they do not focus on the aspects, for example, how AM implementation or usage affects the organizational or people level. This makes it not challenging only for the managerial level to intuitively understand the technology but also for an internal champion might be harder to gain the space and resources for the investment which is not understood in total. To have the required understanding for successful implementation, knowledge must be gathered and spread, and case evidence created step-by-step (see Rad et al. 2022).

In relation to the previous, according to Kyläheiko and Maijanen (2020, 172), organizational renewal is a challenge because of AM´s radical uncertainty. Based on the observation of AM being a complex process where everything depends on different factors related to e.g., the organizational culture, vision, and different resources the aspect of uncertainty about how to implement AM is almost tangible. To put it bluntly, the implementation process might be less vulnerable to carry out when the technology is used as an auxiliary activity rather than aiming for printing critical parts. Unfortunately, at least in AM´s case, failures most likely defeat success. Therefore, it is advisable to pursue the vision of printing critical parts by starting small, e.g., auxiliary activities and this way increase the understanding of the AM and by small and thought-out steps move towards the set goal. With small multiple victories, AM champions can move towards the more critical case examples to win the challenge of stakeholder buy-in which also includes the managerial level, especially if the implementation happens from the bottom-up. Therefore, AM implementation´s biggest barrier seems to be people together with a lack of knowledge. In fact, Neuner and Lang (2019), as well as Butt (2020), emphasize the human-centric viewpoint during the implementation process. In fact, Kamara and Faggiani´s (2021) book as well as Mellor et al. (2014) paper can be held as significant work for AM practitioners because they picture the AM process outstandingly including the organizational and people aspects.

Studying from the sustainability viewpoint Priyadarshini et al. (2022) have found three top barriers to AM implementation, especially the two: high investment to costs as well to R&D and training can strongly be agreed based on this thesis. However, this thesis has not studied the phenomena from a sustainability point of view but has identified the absolute need for knowledge which is why the third barrier named ´Lack of knowledge about AM and its environmental benefits´ can be agreed upon only halfway. It is quite interesting how literature is interested in AM´s sustainability and concentrates on technological aspects of AM technology answering the question of why AM should be implemented leaving the question of how it could be done almost without attention. However, for example, Rad et al. (2022) and Kamara and Faggiani (2021, 158) recognize management as AM´s challenge which can be agreed: the lack of management revealed during the interviews because the questions related to the management of the process usually changed to point out resource shortage and inadequate knowledge.

Additionally, Kamara and Faggiani (2021,3) name the lack of a skilled workforce as a key challenge of AM growth which connects well to the discovered framework and the lack of knowledge found in this thesis. However, based on the analysis the main challenge is not the lack of AM competence workforce, even though it is identified as a problem, the main challenge when it comes to the workforce is the lack of employee training and organizational culture. There is a need to encourage employees to try and explore new technologies and more importantly allow them to fail during the process. Neuner and Lang (2019) mention how the encouragement to think outside the box must originate from the management level while Gehrke et al. (2016) point out the lack of time to pursue innovations.

However, no matter what size the user organization represents, an internal AM champion´s role is essential yet multidimensional and depends on the needs of an organization. In some cases, the internal AM champion is the initiator of the implementation process and sometimes the developer of the company's own AM organization but most importantly s/he is the fuel that drives every AM-related process forward. It is a great asset for an organization considering AM technology implementation if there is already an organizational culture that allows, even courage employees to test and fail without sanctions. Presumably, this also has only a positive effect on the AM champion´s goal to spread the knowledge about AM inside an organization. Organizational culture is emphasized especially when the company has a strategy where AM implementation is cross-sectional and goes beyond department and knowledge frontiers. To confront the challenge related to people, manufacturing organizations need to take action to change the culture and mindset at every level of an organization starting from the managerial level (see Mellor et al. 2014).

6.3 Knowledge, a result of resource allocation

The interviews indicate that without adequate resources the AM implementation is most likely to fail which matches well with the literature´s view of the expensiveness of the technology (see Attaran 2017; Müller et al. 2018; Kamara & Faggiani 2021; Simpson 2022b). In addition, resources can be seen as a challenge as well as an enabler of the whole process. They define the strategy from the knowledge acquisition to the decision whether to buy AM as a service or a printer. Of course, there are other aspects as well defining the strategy like the need and prospects of the company, but the resource challenge emphasizes the need for management´s support during the implementation process. However, to support the implementation also management needs knowledge about AM like different metrics (see Butt 2020; Kamara & Faggiani 2021, 154), such as lifecycle costs and ROI, to make decisions about the strategy and allocating resources. This highlights another challenge of the implementation, how to transfer an intuitive understanding of the technology to the management. Understanding is needed because, as Müller et al. (2018) stated benefits of the AM technology will be realized in the long run.

Business Finland (2021) describes how the amounts of Industry 4.0 technologies implementation vary between large companies and SMEs. Based on the gathered data, this cannot be confirmed nor rejected, but it can be stated that there are a vast number of companies which does not utilize AM in their operations nor even know the basics of the technology. However, large companies indeed seem to have more resources to use for the implementation even though despite their size and easily countable resources they are on the same line with SMEs when it comes to knowledge. Although the company would have all the needed finance to use during the implementation, without AM knowledge, it is a lot harder to succeed in the implementation process. A company, no matter what size, which realizes the absolute need for knowledge, will have the best opportunities to succeed in the implementation process. Knowledge is the base for successful implementation and the result of the allocation of resources such as time, money, and competence.

Consequently, an internal champion´s role can be highlighted in SMEs because there might be fewer resources to use for knowledge acquisition while larger companies can purchase the AM examination from AM service providers or hire a new person to do the examination. Even though the same challenges such as stakeholder buy-in, AM champion, and lack of change management can potentially be found in any sized company, it is presumable that some of the identified building blocks of the three phases are emphasized more than others. For example, the need for the AM core team is individual and depends on the organization’s needs and set goals for AM technology. Also, the strategy defines whether the core team operates AM or does everyone in the organization eventually has AM knowledge. Either way, AM implementation requires the attitude of an entrepreneur (compare to digiproneurship Gibson et al. 2021, 657–660) who keeps things going forward by spreading the knowledge across the departments. For example, stakeholder buy-in is especially a great challenge in large companies as well as industries with a conservative customer base. However, through knowledge acquisition and learn-by-doing phases, an internal champion or AM core team can case by case spread the interest and knowledge about AM.

6.4 Collaboration, together the better

Some AM-using organizations have already operated for many years in the field of AM while others do not even know about AM technology. In Finland, the FAME ecosystem could be called a real supercentre (see Sasson & Johnson 2016) of AM technology which advances the whole field for example by producing and spreading AM knowledge. In fact, FAME can be seen as an important partner when it comes to external collaboration, especially for SMEs that do not necessarily have the resources to acquire and update continuously their AM knowledge on their own. Even though the FAME ecosystem is a significant operator in the Finnish field of 3D technology, its status as an external collaborator is emphasized not until later-stage implementation. An interesting observation from the interviews was that it seems there is a mutual trust at least between Finnish AM operators and a common unspoken goal to make AM technology better known. Partners of the FAME ecosystem benefit indeed of synergy e.g., when it comes to updating their knowledge about the technology. There can be something in common when it comes to the nature of the FAME ecosystem members and Müller et al. (2018) identified a group of proactive implementors of Industry 4.0 technologies in which group members support each other to succeed which creates a good base for new operators entering the field.

Based on this thesis everything begins with knowledge. It is recommended for companies considering AM technology to contact at least at some point an AM service provider firstly to learn by doing, but secondly to have help to e.g., create a suitable strategy for the company to follow. As stated, no one succeeds alone which emphasizes the meaning of collaboration with different groups. However, without eagerness and motivation towards AM technology, an attempt to implement AM could stay just as it is, an attempt. This observation underlines the need for AM champion(s) whose one of the most important tasks is to keep things moving forward, continuously. However, depending especially on the extent of the desired change, the creation of an AM core team or even organization is recommended.

Successful implementation and operation of AM requires collaboration inside and outside the company. There are multiple stakeholders and professionals even inside the company who need to have the required knowledge and work together for a common goal especially when the change is large at scale. These groups include e.g., the management, AM champions, different departments, designers, purchasers, and so on. The literature recognizes the need for reskilling and training the workforce (see Gibson et al. 2021, 639, 540–541, 555; Kamara & Faggiani 2021; Priyadarshini et al. 2022) but at least the research read and used for this thesis does not emphasize a single person´s importance nor the collaboration aspects like this thesis.

However, the implementation of AM is seen as a competitive weapon (see e.g. Kyläheiko & Maijanen 2020, 172; Oltra-Mestre et al. 2021; Truckan et al. 2022) which is a benefit for the whole organization. A bit surprisingly this aspect did not rise from the interviews. Based on the analysis it seems more that the competitive weapon is the Finnish AM community and the FAME ecosystem. The competitive advantage rests on a collaborative mindset and unspoken trust between Finnish AM operators and a collective will to help the industry forward together. Also, it could be assumed that this kind of mutual agency advances Business Finland's (2021) aim for Finnish leadership in Industry 6.0: there could be a lot to learn and benchmark in different fields about the synergies created by the FAME ecosystem.

To sum up, organizations need to ask themselves first, whether are they willing and able to conduct an adequate amount of knowledge through knowledge acquisition and learn-by-doing and where to find an eager person to do the job. When and if AM will be discovered as a suitable technology for the organization it needs to be considered what they want to achieve with AM, for what they are going to use it, and do they have the resources. The given answers will determine e.g., to what extent training should be executed, whether is there a need for an AM core team, and how many members it should include. The early-stage AM implementation requires e.g., change management, suitable organizational mindset, motivated and eager AM champions, continuous development of organizational and personal competence as well enough resources to accumulate knowledge. Especially in relation to the sub-question of this thesis about the challenges and enablers of the implementation process, it can be stated that cornerstones toward the successful AM implementation are like the two sides of the coin: when taken into account, they are enablers of success and when ignored, they can undermine the whole process.

6.5 Evaluation of the limitations of the thesis and further research

During the writing process of this thesis, one thing has become extremely clear; implementation of AM technology is a complex process and a learning journey which makes it an interesting but also challenging research topic. Therefore, outlining the research subject narrowly has been one of the challenges of this thesis. Even though the extent of the AM implementation was understood quite at the beginning of the writing process, the present framing of the subject to the early-stage implementation was discovered in fact after the data analysis. Based on this thesis, implementation of AM can be divided into two stages of which the early-stage implementation has been presented in this thesis. Quite a natural continuum would be to study the later-stage implementation process together with e.g., suitable business models for AM.

In addition, there have been some time constraints regarding especially the number of interviews. Even though the seven completed interviews gave a surprisingly broad view of the AM implementation, the interviews represent quite a small batch of AM experts challenging the question of the generalizability of the qualitative data and the results presented. It also makes to think over whether some aspects have remained unnoticed. However, in qualitative research sample size can be selected purposefully when the aim is to understand the phenomenon in depth, not to find out the general truth (Merriam &

Tisdell 2016, 254). The results of this thesis are based on the qualitative data which provides a contextual understanding of the AM implementation. One more time constraint has been the novelty of AM technology itself as well as the literature about implementing new technologies. Especially at the beginning of the writing journey a great amount of time went to getting to know the technology even a little and to an effort to understand the big picture. As noted, and reflected on what has been learned, one limitation of this study could be the literature focusing more on the footsteps and basics of the AM technology and not perhaps enough on the different theories or concepts about technological implementation in general which in fact would be an engaging further research topic to benchmark already existing implementation frameworks to the context of AM.

Regarding the interviews, the anonymity of experts could be described as a limitation when considering that the expertise is connected to the person and one´s experience with AM technology. A name, an organization, and a short work and education-related biography of each expert could have worked as authorization for the data analysis and made observations. On the other hand, because the Finnish circle of AM experts has been described as rather small, Merriam and Tisdell (2016, 264) warn that it is possible even without mentioning experts´ names, they could be located by the insiders in the field. Also, there is a risk regarding the transcriptions that shortening and detaching from the entity as well as translating the chosen citations from Finnish to English might have unintentionally changed the message or its nuances (see Calder 2020, 95; Hammersley 2020, 375–376).

Regarding the difficulty of outlining the content, a limitation of this thesis is that it is a side project of a research project. The questions were designed in a way that would serve this thesis as well as the project´s purposes. However, almost all data gathered have been presented in this thesis producing multiple insights into the implementation process and raising a question of whether some aspects should have been excluded. On the other hand, the decision to offer observations from the entire data set even at the risk of stretching the research scope too wide was made based on the learning journey and understanding the complexity of the AM implementation process; everything depends on something (compared to Morse and Mitcham 2002; Guest et al. 2012, 38). The same complexity has been also a notable challenge when trying to figure out a sensible way of presenting the results that are in strong relation to one another. For example, external collaboration´s role during the early-stage implementation is not perhaps that significant but the support from AM companies during the knowledge accumulation process is fundamental. Therefore, value and supply chain perspectives on AM are interesting future research subjects.

We are living at an interesting point where at least two, soon perhaps even three or four industrial revolutions might overlap (compare e.g., Abubakr et al. 2020; Michelsen 2020, 1–4; European Commission 2021; Sahu et al. 2022;) which could have great potential for emerging market disruptions and AM. In addition, Kyläheiko and Maijanen (2020), and Müller et al. (2018), as well as one of the experts, offered servitazation as a contemporary or intensifying trend of AM technology. Also, digital warehouses, on-demand production, and sustainability aspects could be seen as future trends of AM. It has been mentioned in the literature for example by Holmström et al. (2010), Neuner & Lang (2019), and Rad et al. (2022) what kind of sustainable effects 3D technology can offer but based on the interviews none of the experts did not raise the aspect into discussion, at least not directly. Yet, this does not indicate that sustainability aspects should not be considered, rather this supports the relationship between Industry 4.0 and Industry 5.0 which the latter brings the sustainability aspects to the center when the paradigm changes or overlaps sometime in the future. AM´s effects on the supply chain and its role in responsible business would be interesting themes to study as well as its nature as a possible disruptive technology.

Indeed, the complexity of the AM implementation process makes it an intriguing and diverse research subject for further research. First, based on the quite small amount of research found about AM implementation from the organizational and people viewpoint, to which this thesis aims to contribute, the validation and further development of created frameworks is required together with new insights towards the implementation journey. There is an urge to create roadmaps regarding the whole implementation process especially for the new AM practitioners and organizations´ managements to offer an intuitive understanding of the implementation process. Furthermore, at the managerial level to embrace the intuitive comprehension of the technology, the value creation of AM must be clear. However, as stated before (see Turckan et al. 2022; Priyadarshini et al.2022) the value aspects of AM technology need to be studied further. To sum up, the exiguity of AM implementation research from the people and organizational viewpoint makes it a versatile future research subject.

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Appendices

Appendix 1 Finland´s path towards Industry 6.0 by Business Finland (2021)

INDUSTRY 4.0: “CONNECT - IOT TO CREATE CYBER-PHYSICAL SYSTEMS FOR ANALYTICS-BASED ACTIONABLE INSIGHTS”	Supply push, production-centered thinking Smart technology at the forefront of manufacturing Interoperability for machines, devices, and people to connect and communicate with each other via internet and other networks at factory floor Digital twins 1.0 Heterogeneous data sources Information transparency, decentralized decisions Technical assistance to support people by aggregating and visualizing information Functional materials provide new opportunities
INDUSTRY 5.0: “CO-EXIST - HUMAN-MACHINE CO-CREATIVE RESILIENT AND SUSTAINABLE CYBER-PHYSICAL SYSTEMS FOR MASS-CUSTOMIZATION”	Mix of supply push and demand pull Human in focus Increased collaboration between humans and smart systems, cobotics Mass-customization enabled Circular economy in focus Sensor networks and edge computing for environment analysis Re/de-manufacturing Zero waste, zero emission Digital twins 2.0 providing understanding not only about the factory-processes but the whole environment Complexity increase2 Product complexity is increasing as a result of the adoption of advanced technologies in products and processes and ever-increasing customer expectations The complexity of value networks is steadily increasing
INDUSTRY 6.0: “UBIQUITOUS - CUSTOMER DRIVEN VIRTUALIZED ANTIFRAGILE MANUFACTURING”	Demand pull, customers in the centre of thinking Hyperconnected factories in complex, dynamic supply chains and value networks, where data flows across different administration domains. Requires a common data model. Human digital twin connects manufacturing For example, take a picture of a rough sketch and click “make it” Role of human dramatically changes in manufacturing Sort of analogy from ICT, production is like cloud capacity, “factories” sell production capacity similarly to, e.g., Amazon selling computing capacity AI optimizes the production to obtain sustainability and antifragility lot-size-1 made economically feasible Antifragility obtained via the design of systems relying on Non-Functional Requirements (NFR) - thinking

Appendix 2 Semistructured interview questions

<table>
<tr><th colspan="2">Questions for all case companies</th></tr>
<tr><td colspan="2">• Could you tell me about your work history and how you ended up in your current role?
• What is your company's relationship with AM technology?
• Is your company's business born digital, or has AM been incorporated as a new technology into the business?
• Why has your company decided to engage with AM technology?</td></tr>
<tr><th>Questions for AM service providers</th><th>Questions for AM user companies</th></tr>
<tr><td>Implementation:
• What are the typical stages in the implementation process at the organizational level?
• What changes does the implementation of AM technology require within the company?
• How is the decision to implement AM technology typically made in companies that contact you?
• Who makes the decision to implement the AM technology?
• How is the responsibility for implementation distributed within the organization?</td><td>Implementation:
• Who made the decision to implement AM?
• What stages have you gone through at the organizational level in the implementation of AM technology?
• What changes does the implementation of AM technology require?
• How is the responsibility for implementation distributed within the organization?
• How did the management justify the implementation?
• How have employees reacted to the new technology?</td></tr>
<tr><td>Implementation challenges:
• What kind of challenges do companies face in the implementation of AM technology?
• How are these challenges overcome?
• What kinds of issues do you typically get approached?</td><td>Implementation challenges:
• Were there any challenges encountered during the implementation?
• How did you overcome these challenges?</td></tr>
<tr><td>Knowhow and collaboration:
• What kind of expertise do companies need when adopting AM technology?
• How do companies acquire the expertise required?
• What is the significance of collaboration in this field?</td><td>Knowhow and collaboration:
• What kind of expertise has been required during the implementation?
• Where or how was the expertise acquired?
• What significance does collaboration hold in this context?
• What role has change management played in the entire process?</td></tr>
</table>