# IMPLEMENTATION OF ADDITIVE MANUFACTURING TECHNOLOGIES FOR MASS CUSTOMISATION

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## ABSTRACT

With rapid technological progress in additive manufacturing (AM), enterprises are increasingly attempting to utilise the technology for mass customisation. This study investigates the managerial and technical implementation challenges that these companies face. We adopted a qualitative research design with a case study based approach. Data were gathered from secondary sources and semi-structured interviews to form three case studies with companies involved in adopting AM for mass customisation.

Our research found that existing studies on the economics of higher scale production for AM needs to be expanded. In the literature, traditional manufacturing systems are believed to be more cost efficient than AM for higher production volumes. However, case studies yield results that show the opposite. The data suggest that in certain industry sectors AM adopts the role of a mass production technique. Low tolerance levels for mistakes, time pressure to process orders and technical restrictions in raw material supply and machine modifiability have been identified to be a major challenge in the implementation of AM for mass customisation.

These results provide insights to support the development of a framework of AM implementation which will benefit decision makers in companies and policy makers who are considering to invest in AM.

Key words: Additive Manufacturing, Rapid Manufacturing, Mass Customisation, Technology Implementation

## INTRODUCTION

Industrial companies act in a highly dynamic environment which forces them to develop and produce at a high level of flexibility and quality at low costs (Schleifenbaum, Diatlov, Hinke, Bültmann, & Voswinckel, 2011). Schleifenbaum et al. (2011) argue that trends of production in high wage countries can be reduced to two inherent dilemmas, one of these being the scale-scope dichotomy of production:

i. A production system is either designed for high scale output with little variances in terms of product design or

ii. it is designed for individual products with a high variety in design but limited to small batch sizes.

In order to deal with the scale-scope problem that most high wage countries are facing at the moment, the concept of mass customisation, which connects the seemingly contradictory principles of mass production and customisation, has been suggested by academics and governmental institutions (Brecher, 2012). The German National Foundation of Research and the UK Technology Strategy Board (TSB) have identified additive manufacturing (AM) and mass customisation (MC) as two of the most important processes/strategies to ensure high value manufacturing in both Germany and the UK (Technology Strategy Board, 2012). Increasing investment into AM technologies both on a corporate as well as on a governmental level in the US, UK, Germany, China and Japan in recent years has progressed the capabilities and application range of AM technology rapidly (Wohlers, 2013). Despite the technology having existed for over 20 years as a means to produce prototypes with very limited mechanical functionality, only recent developments within the last decade have initiated the applicability for end products (Gebhardt, 2011).

The paper explores how AM technology is implemented by companies in regard to higher scale customised production. We investigate the technical, economic and business management challenges associated with such implementation. The research aims to contribute to the literature gaps for Rapid Manufacturing, Mass Customisation and Advanced Manufacturing Technologies implementation frameworks.

The study is structured into four parts. First, we review the literature on Rapid Manufacturing, Mass Customisation and Implementation of Advanced Manufacturing Technologies. Second, the methodology is presented regarding research design, case selection and case study company background. Third, research results are discussed and compared to existing theories presented in literature. The final part presents conclusion and future research opportunities.

## LITERATURE REVIEW

### Rapid Manufacturing

Hopkinson et al. (2006, p.1) define Rapid Manufacturing (RM) as

> "the use of a computer aided design (CAD)-based automated additive manufacturing process to construct parts that are used directly as finished products or components".

The term additive manufacturing (AM) refers to "the process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies" (ASTM, 2012, p. 2). AM can be classified according to the method of material supply into liquid based, solid based and powder based systems (Wong & Hernandez, 2012). Fig. 1 displays a selection of the most industrially relevant AM-processes. The case studies within this study deal with the processes of Selective Laser Sintering (SLS), Selective Laser Melting (SLM), Stereolithography (SL), Direct Metal Laser Sintering (DMLS).

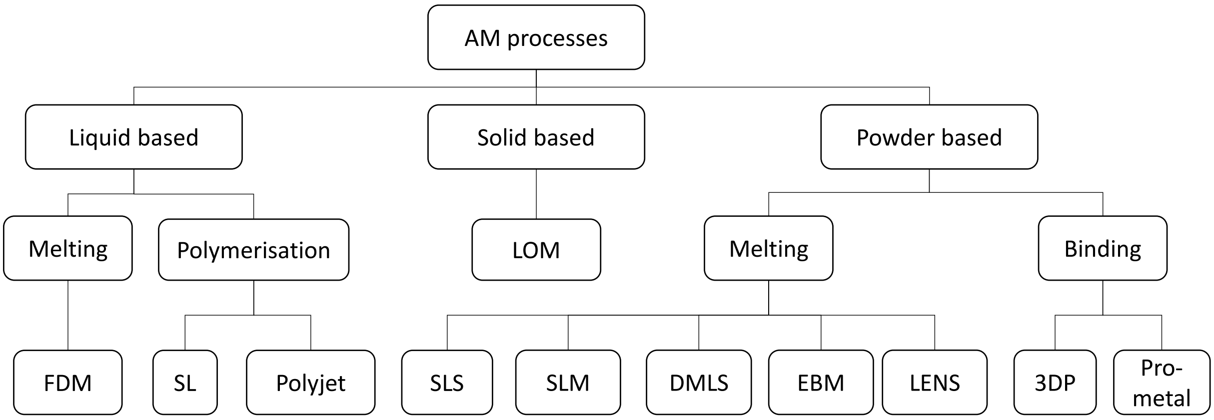


*Fig. 1: Classification of additive manufacturing technologies based on Wong & Hernandez (2012)*

RM derived from the term rapid prototyping (RP) which was used first in the 1990s to describe the quick creation of prototypes (Atzeni, Iuliano, Minetola, & Salmi, 2010). The manufacture of prototypes could be realised either by addition or subtraction of material (Pham & Dimov, 2001). The technology utilised in RP was later employed for the production of tools which was termed rapid tooling (Pham & Dimov, 2003). Rapid tooling can be realised indirectly through the creation of intermediate tools such as moulds and through the direct manufacture of tools through AM (Pham & Dimov, 2003). Initially insufficient mechanical properties of the produced objects (Kruth, Levy, Klocke, & Childs, 2007) have been improved as the result of increased R&D in AM within the last 5-10 years allowing for the emergence of RM (Mellor, Hao, & Zhang, 2014).

Holmström, Partanen, Tuomi, & Walter (2010) attribute the following benefits to AM technology employed for RM:

i. Absence of tooling requirements reduces production time and expenses
ii. Small production batches become feasible and economical
iii. Quick design changes are possible
iv. Production can be optimised in regard to functional purposes
v. Custom products become economically viable
vi. Waste is reduced
vii. Supply chains can be simplified
viii. Design of products can be customised

Comparative costing models between RM and traditional manufacturing processes have been analysed by Ruffo, Tuck, & Hague (2006). Fig. 2 illustrates the break-even point at which the costs for the conventional manufacturing (Injection Moulding) process start becoming less than for AM as the number of parts produced increases. Existing literature appears to suggest that traditional processes are more economically viable in high output quantities (Hague, Mansourj, & Salehf, 2004; Hopkinson & Dickens, 2003).

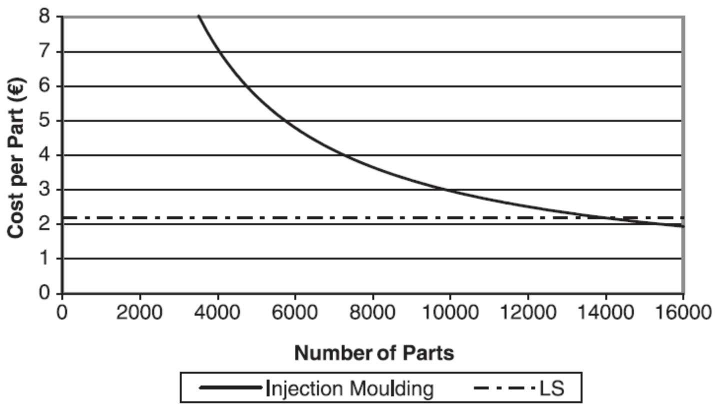


*Fig. 2: Break-even analysis: Laser sintering, injection moulding (Ruffo et al., 2006)*

Production strategies considering the number of parts and their orientation and location within an AM machine have been discussed by Ruffo et al. (2006). The cost per part decreases if a certain number of parts can be accommodated within a run which thus warrants the filling of a powder bed (Fig. 3).

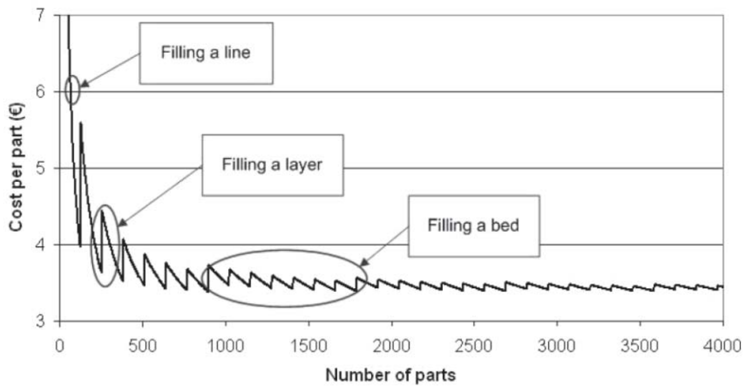


*Fig. 3: Cost behaviour SLS production (Ruffo et al., 2006)*

The inherent benefits of AM as discussed by Holmström et al. (2010) in theory allow the realisation of production strategies such as mass customisation as it allows customisability of products (Fogliatto, da Silveira, & Borenstein, 2012). Reeves, Tuck, & Hague (2011) and Gibson, Rosen, & Stucker (2010) discuss the potential of RM for MC approaches. The literature on RM and MC, however, either only describes future applications and implications for MC and RM or mentions existing examples in the medical industry (specifically hearing aids, dental products and surgical applications) and consumer goods industry in an informative way without investigating the industrial and technical context further (Gibson et al., 2010).

After a review of literature, Mellor (2014) finds that the following barriers exist in the context of RM implementation:

i. High capital investment

ii. High material and maintenance costs

iii. Insufficient material properties
iv. Difficulties with material removal
v. High process costs.

Generally literature on RM, and consequently on RM and MC, appears to be based on hypothetical and potentially outdated cases, thus displaying the lack of AM application cases that have been studied. As such, there is a need to reinvestigate the old identified challenges and to explore the current state of RM adoption, especially in the light of fast technological progress within recent years (Khajavi, Partanen, & Holmström, 2014).

**Mass Customisation**

The term "mass customisation" was originally coined by Davis (1987) to describe the contradictory production strategy of realising mass production of customised objects; the principle was later developed by Pine (1993) (Duray, 2011). The underlying theory in literature for mass customisation is based on Hayes & Wheelwright's (1979) product process matrix (Duray, 2011). Within the product variety matrix adopted in literature (Krajewski, Ritzmann, & Malhotra, 2007; Schroeder, 2007; Stevenson, 2009), MC attempts to bridge classic mass production and one-of-a-kind production. Fig. 4 depicts the positioning of mass customisation approaches within the discussed matrix between mass production in the lower right-hand corner and production of different individual products in the top left-hand corner (Tuck, Hague, Ruffo, Ransley, & Adams, 2008).

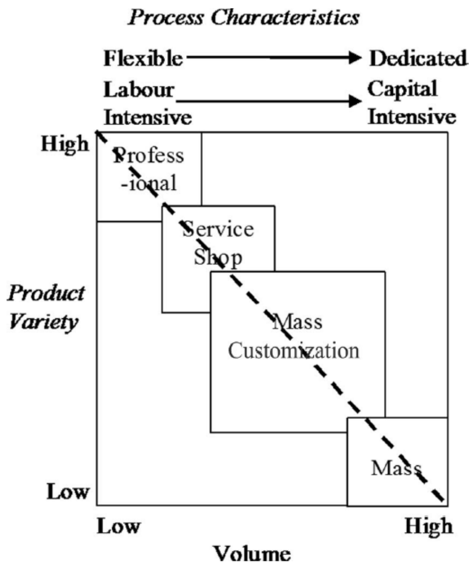


*Fig. 4: Product variety-volume matrix (Tuck et al., 2008)*

The term "customisation" implies that the customer has to be involved in the design process at some point in the product creation process (Mintzberg, 1988). Mintzberg (1998) classifies customisation into the three categories of pure, tailored and standardised with each stage differing from the other in terms of its uniqueness and the degree to which a customer is involved. The earlier the customer is involved in the production process, the higher the degree of customisation.

Academics trying to define the level of customisation and production volume required that qualifies the term MC do not appear to reach a consensus in the MC literature (Bateman & Cheng, 2006). On one side there are advocates of MC that believe that MC only exists if the customer can fully customise the object in every regard, on the other side more pragmatic scholars consider the product creation and delivery according to some customer requirements to constitute MC (Silveira, Borenstein, & Fogliatto, 2001). Hart (1996) believes that the compromise for these divergent views is to identify the realistic and appropriate range of customisability of a product and how customers make demands on this range. Westbrook & Williamson (1993) think that MC can only be successfully implemented if customisability is combined with standardised processes that offer high part variety. Similarly, literature does not specifically define the level of production units required related to MC. Instead, Duray, Ward, Milligan, & Berry (2000) and Pine (1993) suggest that production costs of MC should ideally be close to mass production levels.

To make MC economically viable, Pine (1993) suggests the degree of customisation be limited to the customer. Specifically, the principle of modularity in the product creation process is to combine standardised and customisable components. Modularity realises the feasibility of producing objects on a “mass” scale while variable elements ensure the customisation aspect. Many scholars believe that MC for the creation of physical products has to be restricted and combined with modularity in order to successfully work (Duray, 2011; Piller, Moeslein, & Stotko, 2004; Piller, 2008; Pine, 1993). Silveira et al. (2001) claim that one of the core activities for a successful implementation of MC is the concentration on value and the elimination of waste in all production steps and the reorganisation of value-creating activities into efficient processes at high variant and production levels.

The literature on MC has significantly increased from 2001 with the emergence of web-based software tools, the development of systematic customer-interaction models and the emergence of RM technologies (Fogliatto et al., 2012). Fogliatto et al. (2012) have reviewed literature on MC and classified it into four different literature areas. The body of literature on MC can be divided into a category describing the economics of the principle, into one investigating success factors, into MC enablers and into customer-manufacturer interaction.

With the aforementioned benefits of AM technology and RM, particularly in regard to the degree of customisation, this study aims to target the literature body of MC enablers which can be further classified into four categories describing methodologies, processes, manufacturing technologies and information technologies (Fogliatto et al., 2012; Silveira et al., 2001). Literature on MC enabling manufacturing technologies has so far primarily focused on computer-aided design and 3D laser scanner in the clothing, garment and shoes industries (Fogliatto et al., 2012). A literature search conducted by Fogliatto et al. (2012) reveals the lack of research on implementation models of manufacturing technologies for MC. Despite recent research attention of RM technologies for MC, the literature appears to be still scarce. Similarly, barely any studies seem to have targeted the business management implications of RM and MC (Fogliatto et al., 2012).

**Framework for Advanced Manufacturing Technology implementation**

Voss (1988) identified four factors that have an influence on successful implementation of AMT from three previous studies by Voss (1985), Ettlie (1984) and Buchanan (1985), namely organisation, technology, business strategy, management issues. He aligns influencing factors for the implementation of AMT along his life-cycle model of implementation. Building on the research by Voss (1988), Chen & Small (1994) developed a planning model for AMT implementation specifically targeting operational and organisational factors. Small & Yasin (1997b) expanded the planning model through survey insights.

Focussing on factors influencing AMT implementation, Saberi et al. (2010) propose a framework of effective factors that have an influence on AMT implementation which distinguishes between technological, organisational and internal and external variables (Fig. 5).

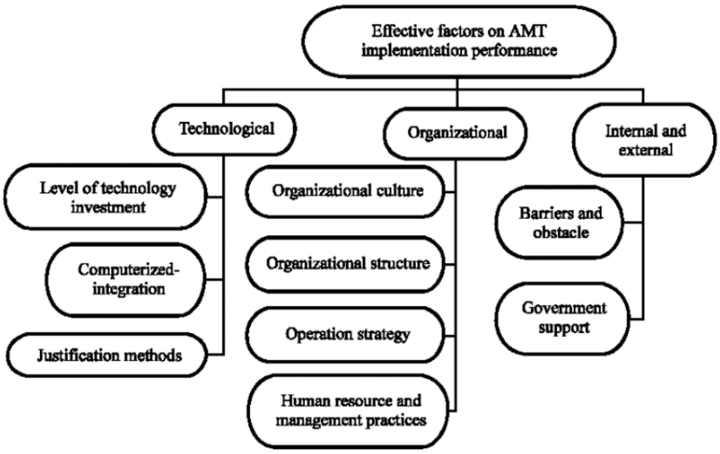


*Fig. 5: Contextual factors influencing company performance (Saberi et al., 2010)*

Further work for AMT implementation has been carried out by Singh, Garg, Deshmukh, & Kumar (2007) who develop an interpretive-structural model for effective AMT implementation and by García & Alvarado (2012) who identify problems in the AMT implementation. The main identified problems in those publications were related to maintenance, installation and setup, supplier relationships, investment justification process, decision and analysis process, lack of knowledge customs, and failures and differences with ordered AMT.

A framework specifically for AM adoption is proposed by Mellor et al. (2014) by considering strategic, supply chain, operational, organisational and technological factors. The framework, however, is limited by the low number of sample case studies from which the framework is derived.

Our review has revealed that with the benefits and advances of AM technology, RM has the potential to become an enabler for MC. While there is research on RM, MC and implementation frameworks, there is a gap around a topic that focusses on these three fields of research combined. Despite literature and regulatory bodies underlining the necessity to investigate how AM facilitates MC, there are no appropriate studies on the topic.

## METHODOLOGY

### Research design

Adopting and modifying the architecture of the framework proposed by Saberi et al. (2010) and Mellor et al. (2014), a framework has been created with a particular focus on technological variables. The technology factors in the production creation process through AM have been categorised into front-end factors comprising data-preparation and applied software, into machine related factors such as raw material supply, maintenance issues, production capacity and surface quality, and into back-end factors that comprise post-processing steps. These factors and the clustering were derived from literature (Hopkinson, Hague, & Dickens, 2006b; Tuck et al., 2008) as well as from interviews with experts in industry and academia (Fig. 6). The factors influencing AM implementation for MC are categorised into technological, operational, organisational and internal/external factors (Fig. 7). The purpose of the framework is to ascertain the importance of different factors influencing the implementation of AM for MC and to provide a format in which information gathered in case studies can be clustered.

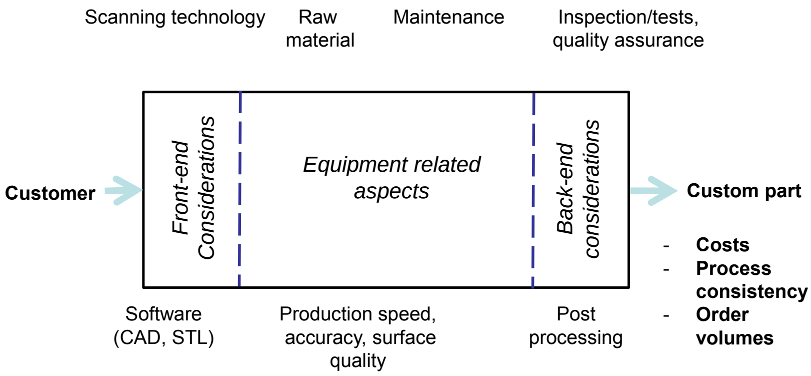


*Fig. 6: Technology factors in the AM production creation process*

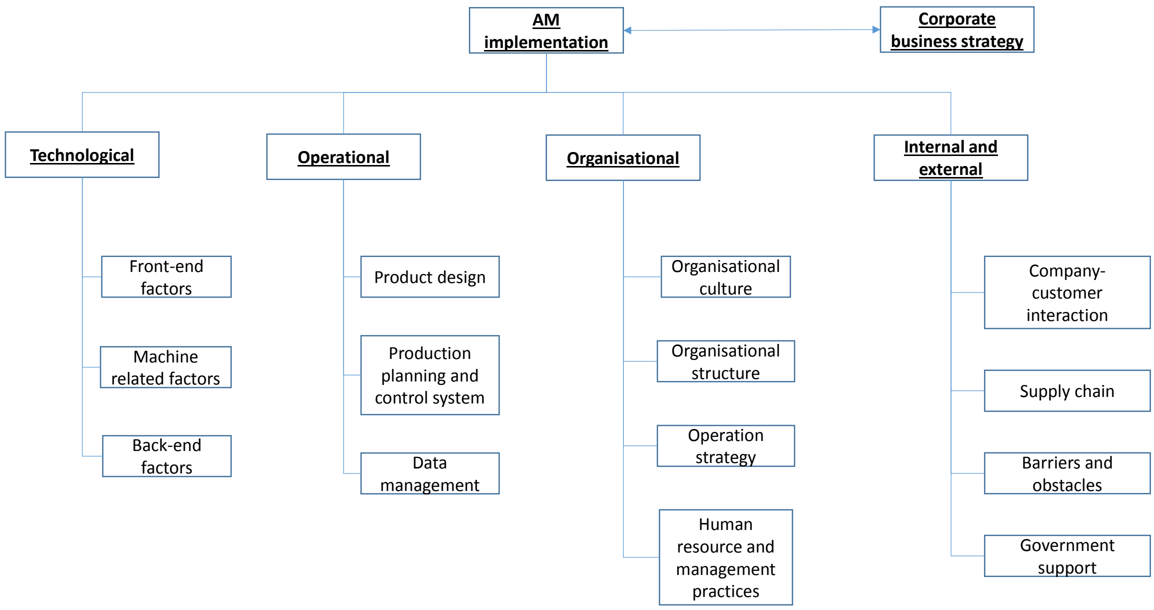


*Fig. 7: Framework for AM implementation for MC*

In an initial step, the research is aimed at identifying industry sectors that provide appropriate data. In line with Yin (2009), the industry had to provide an appropriate data basis for the research focus and the data had to be accessible. In the context of the research, this translates into

i. selecting industries with a sufficient degree of AM technology maturity and level of implementation of AM,

ii. identifying industries that offer cases in which AM technology is applied for mass customisation:

iii. Industries that see the value of AM in the customisation of their products,

iv. Industries that use AM on a production level between mass produced and service shop scales as presented by Tuck et al. (2008). This value is an industry dependent value.

An analysis of industry reports and interviews with leading experts in industry and academia identified the medical industry and the consumer goods industry as appropriate industry sectors. Table 1 lists the contacts with whom 45 min interviews or academic workshops have been conducted. Within the medical sector, dental, hearing aid applications and surgical implants have been identified to provide appropriate data bases. These industries offer products that fulfil the requirement for necessary production output as well as producing customised items.

*Table 1: List of interview contacts*

| Position | Affiliation |
|---|---|
| **Leading academic on AM** | University of Nottingham, Faculty of Engineering |
| **Managing Director** | Consulting company specialised in AM |
| **Senior Researchers** | Fraunhofer Institute for Laser Technology |
| **Leading academic on Mass Customisation** | RWTH Aachen University, Chair for Technology and Innovation Management |
| **Senior Researcher** | Large German automotive company |
| **R&D lead project manager** | Large German automotive company |
| **Senior Researcher** | Chalmers University of Technology, Chair of Innovation Management |
| **Chief production engineer** | US based AM-supplier for automotive industry |
| **Marketing and business development manager** | UK based large multinational engineering company |
| **Manager technical services for dental products** | AM service bureau |
| **European product manager** | AM service bureau |
| **Researcher** | Cambridge University, Centre for Industrial Photonics |

The main part of the research consists of three case studies of companies that are implementing AM for MC. Data has been gathered through semi-structured interviews with informants within the company and through secondary data.

**Case selection**

The primary target for the case study selection are companies that offer a service of producing mass customised objects through an AM process.

The selection process of narrowing down possible case study companies was a two stage process as recommended by Yin (2009): An initial list of companies active in AM was compiled from existing research consisting of past master theses, from review of literature, online searches and interviews. In a second stage, the list was reduced by selecting case companies that operate within the identified industries and which produce end products additively in appropriate numbers and with enough customisation characteristics. Two types of companies have been identified from literature and through interviews with leading academics and industry experts that contribute to a case.

i. Service providers, also known as service bureaus, which tend to be relatively small to midsized companies that acquire AM-systems and sometimes modify the technology in order to sell parts.

ii. Companies that are utilising AM-technology in-house to produce products.

Manufacturers of AM systems were identified as a third type to supplement and solidify the data base, especially in regard to technical aspects of AM which may not be answered sufficiently by AM systems users. In some cases these manufacturers also offer an integrated bureau service so that they qualify as companies described in ii.

**Company background**

Company A is a global engineering company operating in the medical, aeronautics and high technology engineering and electronics sector for AM. The study focuses on the dental operations of the enterprise in regard to AM. Having established a presence in the dental sector by supplying equipment, the company decided to manufacture products for the dental industry. Since the market required a cheap way of producing dental copings made out of metal, the company moved into additive manufacturing. The company both provides the service of producing dental products additively with SLM and sells SLM-machines to clients. The informants are the marketing and business development manager for dental products and the senior development engineer of the dental products division.

Company B is a company with a long history and expertise in the processing of precious metals. The enterprise has planned to launch a DMLS-AM-machine designed to produce items made from precious metals for the luxury goods industry. The machine has been developed in collaboration with a major AM-manufacturer specialised on Selective Laser Sintering. The informant is the European product manager with 25 years of work experience with the company.

Company C is an AM company that provides AM software for data preparation and offers an AM service bureau for the creation of prototypes and end-parts for various industry sectors. Despite offering AM services for various materials, the company's core competence lies in the production of polymers. The informant is the manager for technical services and has experience as a product manager for laser sintering and fused deposition melting (FDM) within the enterprise.

The challenges faced by the three companies have been assessed according to the drawn up framework (Fig. 7).

**RESULTS AND DISCUSSION**

This section presents the research results clustered according to the suggested implementation framework (Fig. 7) and compares these with theories in literature.

**Technological factors:**

Technological considerations are divided into front-end factors, machine related factors, back-end factors and overall process challenges according to Fig. 6.

*Front-end considerations*

On a technical level, data preparation and front-end activities are usually executed through software developed by company C. The software appears to be robust in dealing with data files. For the AM process and its optimisation, the design can sometimes be optimised for better printing and support structures have to be created. Companies implementing AM have to allocate resources for these steps.

*Equipment and machine related factors*

In regard to the machine, powder handling and transport poses major challenge in all investigated case companies. Within AM for polymer, the market is dominated by two companies (EOS and 3D Systems) so that prices are relatively high at the moment of investigation. Maintenance and extensive modifications of AM machines are often difficult as all AM-manufacturers close their system in order to offer powder supply and maintenance service contracts. This can prove to be a problem for enterprises that are coping with larger order volumes and multiple AM-machines, as they may want to be able to fix a technical maintenance problem as soon as internally possible in order to reduce machine downtime. In terms of production speed and machine capacity, it needs to be evaluated what position AM-processes take within an adopted market sector. For polymer AM applications at company C, the processes cannot compete with traditional manufacturing like injection moulding on large scales (up to 10,000 parts) which confirms the cost-estimation model put forth by Ruffo et al. (2006). However, in the dental industry AM adopts the position of a mass production technique: AM operations are scalable and are most economical in high order volumes. This defies the generalisability of current research executed on comparative costing models between AM and traditional manufacturing processes (Fig. 2).

*Back-end challenges*

Surface quality and mechanical properties are similar to conventionally produced goods but pose a challenge as it requires post-processing. For dental applications, heat and surface treatment is essential to attain the expected standard. Another risk factor is the manual removal of parts from the build platform as it may result in damaging the product.

*Overall process challenges*

Overall process challenges are operating within a short time frame and producing products which are all different in shape and size. The process has to be made efficient with a minimum of overhead as soon as production is scaled. The MC approach, combined with the time pressure and operation strategy of fitting as many parts as possible in one production run, results in the challenge of only having one opportunity to produce every part according to an acceptable standard.

Operational factors

On an operational level, product design poses the challenge for AM-implementers that customers are often unaware of the design possibilities and restrictions. This may result in the need to educate the customer and to fix and optimise some of the submitted designs. Production planning and control systems are crucial in all evaluated cases for controlling for the quality of the process output. Incorporation of sacrificial parts and in-process control systems have to be considered as an essential part when operating AM in an MC-approach. Equally, job management systems have been identified as the backbone for reducing overhead costs and streamlining operations. In the analysed cases, the AM-activities usually originated from existing expertise in a relevant market; synergy effects and knowledge from other departments were utilised in the AM-department.

**Organisational factors**

The operation strategy for AM-systems vendor is characterised by offering comprehensive customer support and by deriving revenues from powder supply and maintenance service. Companies that are implementing AM for MC have followed an operation strategy of automating as many activities as possible and using resources and time as efficiently as possible, for instance initiating the AM-build process only during the night. Implementation of AM for polymers can be characterised by tailoring operations around the attempt to achieve process consistency.

**Internal and external factors**

In terms of customer and company interaction, companies will have to spend resources on marketing and educating customers for them to realise the full range of customisation benefits offered by AM. From a supply chain perspective, AM suppliers will have to be able to manage the transportation of powder. For companies who produce domestically and distribute globally, the supply chain has to be well coordinated with manufacturing activities. In most analysed markets, the raw material supply is limited to the system's producer. One of the barriers that inhibits successful implementation is the fact that AM is not well established in most markets and that most potential customers have a conservative view and prefer conventional manufacturing processes or even dismiss AM-products as having the mechanical and functional properties of RP-products. An additional problem is the current position that AM-systems vendors are assuming: Systems are "closed" to their own services and do not allow for alteration by the customer which presents an impediment for scaling-up production with AM. AM-suppliers for polymers also do not appear to strive for process output consistency as much as the ones for metal AM do.

**Comparison of results with literature**

The case study results highlight several areas of alignment but also contrast with the literature on RM, MC and AMT implementation frameworks

*AMT-framework implementation (for MC)*

Comparing the research results with existing research, the following challenges that have been identified in the reviewed literature can be confirmed: High capital investment, high material and maintenance cost and difficulties with material removal as inhibiting factors for AM implementation were observed throughout all three case studies. On the other hand,–the significance of technological and operational factors appears to be more important than previously anticipated by Mellor et al. (2014). A more detailed investigation into the utilised case companies revealed significant changes in organisational structure and unidentified challenges.

Two examples of major challenges that have been identified for the implementation of AM for MC that have not been assessed in depth in literature are a low tolerance level for mistakes and a high degree of time pressure to process orders. Attempts to scale up production are inhibited by limitations set by machine vendors through closing material supply for their machines and through limiting adjustability of machine parameters. AM-implementers for MC face the challenge of acquiring and training personnel for their operations. Additionally, since AM as a manufacturing process is just emerging in the studied industry sectors, resources will have to be spent on marketing in order to make customers aware of the possibilities and limitations of AM.

*Mass Customisation*

The research results derived from the case studies confirm the theory proposed by Silveira et al, (2001) that there is a strong requirement for production efficiency and agility when MC is applied in manufacturing. When attempting to scale-up production for MC, the investigated companies rely on reducing overhead and process costs in order to realise competitiveness against traditional manufacturing processes and against competition from companies producing in lower-wage economies.

*Rapid Manufacturing*

Existing cost models as proposed by Ruffo et al. (2006) have to be limited in generalisability as they do not appear to be applicable to AM in the dental industry.

The insights gained from the case studies only appear to either be partly congruent with some of the other identified challenges associated with RM or not applicable. Whereas insufficient material properties can only be observed to a certain degree for AM for polymers, it does not apply to AM in metal. The technological progress in metal AM has realised processes that produce mechanically robust objects. High process costs are being minimised in AM and MC approaches through automating activities and tasks.

**CONCLUSION AND LIMITATIONS**

The study results highlight the lack of research on implementation frameworks of AM for MC. While some theories in literature on RM, MC and implementation frameworks of AMT can be confirmed by the study, a large proportion of literature appears to be insufficient to capture how AM facilitates larger scale production of individualised products. This is partly attributable to the fast technological progress of AM technology in recent years. Existing studies fail to capture the technology and operational challenges associated with scaling up production for AM.

The study is part of an ongoing research project and aims to develop a framework of AM implementation for MC. The framework drawn up from literature and interviews with industry experts and academics is subject to modification based on the insights derived from case studies. At this stage of research, due to the low number of case studies the insights merely serve as indication for the importance of the suggested framework factors.

The generalisability of the findings are constrained by the low number of case studies conducted and the fact that the investigated companies stem from different industry sectors. Future research should target increasing the number of cases within the identified industry sectors. A larger data basis of case studies would benefit the refinement of the suggested framework and will provide more evidence for insights derived in regard to theories in literature. In particular, a higher number of cases within the dental industry, consumer goods and luxury goods industry as well as investigation of other medical areas such as hearing aids and surgical implants will extend the research. Another potential limitation that the study faces within the research context of additive manufacturing is the validity of the research insights in the face of quick technological advancements and changes.

The study is subject to methodological limitations. For the analysis of empirical data, the thesis sought to reduce the subjective bias associated with single-person research as far as possible. In particular, this applies to the conducted interviews. Despite the fact that the interview candidates were chosen according to criteria such as duration of employment with the analysed company, and professional and academic background, variations in personality can imply subjective bias.

Future work will consist of further case studies in the dental, hearing aids and surgical implants and luxury goods industry. Insights from these cases will provide the data basis for a framework for implementation of AM for MC.

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