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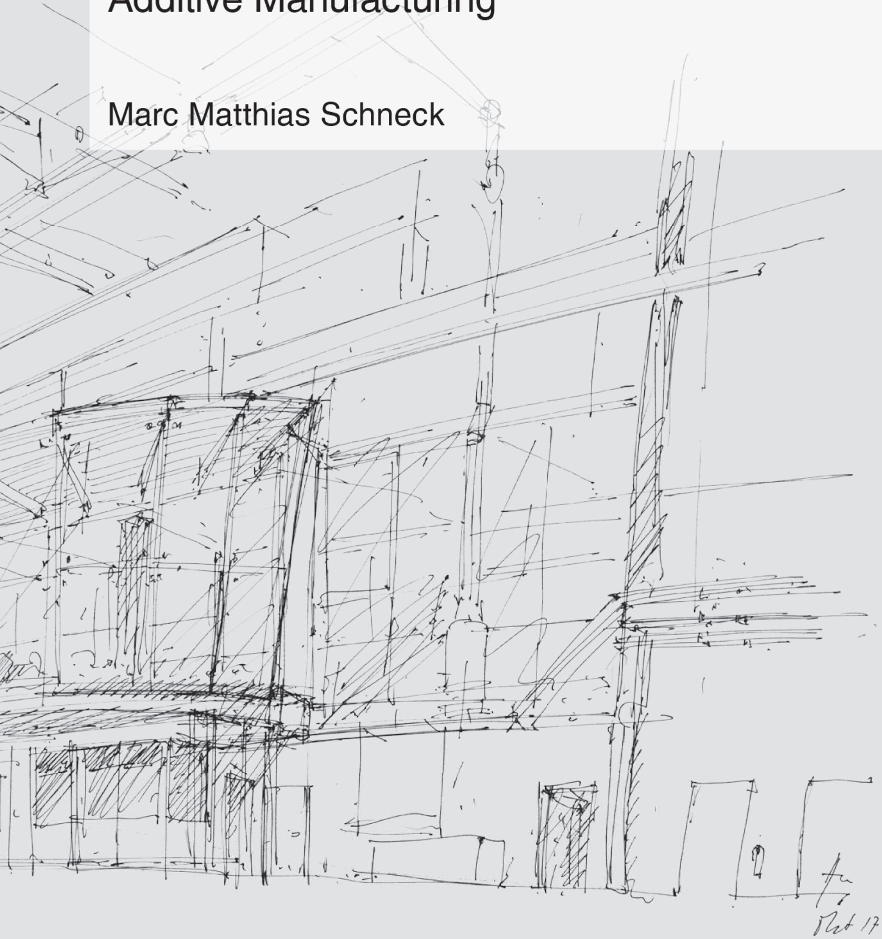
Technology Strategy for Metal-based Additive Manufacturing

Marc Matthias Schneck



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Marc Matthias Schneck

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Geleitwort der Herausgeber

Die Produktionstechnik ist für die Weiterentwicklung unserer Industriegesellschaft von zentraler Bedeutung, denn die Leistungsfähigkeit eines Industriebetriebes hängt entscheidend von den eingesetzten Produktionsmitteln, den angewandten Produktionsverfahren und der eingeführten Produktionsorganisation ab. Erst das optimale Zusammenspiel von Mensch, Organisation und Technik erlaubt es, alle Potentiale für den Unternehmenserfolg auszuschöpfen.

Um in dem Spannungsfeld Komplexität, Kosten, Zeit und Qualität bestehen zu können, müssen Produktionsstrukturen ständig neu überdacht und weiterentwickelt werden. Dabei ist es notwendig, die Komplexität von Produkten, Produktionsabläufen und -systemen einerseits zu verringern und andererseits besser zu beherrschen.

Ziel der Forschungsarbeiten des *iwb* ist die ständige Verbesserung von Produktentwicklungs- und Planungssystemen, von Herstellverfahren sowie von Produktionsanlagen. Betriebsorganisation, Produktions- und Arbeitsstrukturen sowie Systeme zur Auftragsabwicklung werden unter besonderer Berücksichtigung mitarbeiterorientierter Anforderungen entwickelt. Die dabei notwendige Steigerung des Automatisierungsgrades darf jedoch nicht zu einer Verfestigung arbeitsteiliger Strukturen führen. Fragen der optimalen Einbindung des Menschen in den Produktentstehungsprozess spielen deshalb eine sehr wichtige Rolle.

Die im Rahmen dieser Buchreihe erscheinenden Bände stammen thematisch aus den Forschungsbereichen des *iwb*. Diese reichen von der Entwicklung von Produktionssystemen über deren Planung bis hin zu den eingesetzten Technologien in den Bereichen Fertigung und Montage. Steuerung und Betrieb von Produktionssystemen, Qualitätssicherung, Verfügbarkeit und Autonomie sind Querschnittsthemen hierfür. In den *iwb* Forschungsberichten werden neue Ergebnisse und Erkenntnisse aus der praxisnahen Forschung des *iwb* veröffentlicht. Diese Buchreihe soll dazu beitragen, den Wissenstransfer zwischen dem Hochschulbereich und dem Anwender in der Praxis zu verbessern.

Gunther Reinhart *Michael Zäh*

Gib dein Bestes.

Dann warte in Gelassenheit auf das Ergebnis.

Mehr als du tun kannst, kannst du nicht tun.

Weisheit der Stoiker

Danksagung

Mein herzlicher Dank gilt allen, die zur Entstehung und zum Gelingen dieser Arbeit beigetragen haben.

Zu allererst gilt er Herrn Prof. Dr.-Ing. Gunther Reinhart für die Betreuung dieser Arbeit und die stete Begleitung des zugrundeliegenden Kooperationsprojekts. Weiterhin gilt er auch Herrn Prof. Dr. Peter Mayr für die kritische Durchsicht und die Übernahme des Korreferats.

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Im Oktober 2021

Abstract

Metal-based Additive Manufacturing (AM) technologies are promising for achieving innovations in products and manufacturing processes. Thus, many manufacturing companies have a need to evaluate such technologies' potential but struggle with the complexity of the process and the lack of internal expertise concerning AM, which hinders a structured technology implementation.

To support the strategic implementation of metal-based AM, a methodical approach for developing an *AM Technology Roadmap* is generated on the basis of a company's requirements and product portfolio. The process to obtain the roadmap is divided into three fields of action. Action field A entails gathering technology information, which is then summarized in a *Technology Fact Sheet*. In action field B, suitable applications for AM technology are identified through a combined data- and knowledge-based screening approach. The applications are evaluated on the basis of an *Application Assessment Sheet*, which considers the benefits of AM technology and a technical–economical evaluation. In Action field C, organizational tasks for AM adoption are derived, focusing on the sourcing of the AM technology through a make-or-buy evaluation and measures to generate and exchange knowledge about AM technology. The results of the three action fields are aggregated as connected, time-based planning objects in the *AM Technology Roadmap*.

The applicability in the industrial context is demonstrated through six use cases from various industries. In conclusion, the approach provides a valuable structured support with which to assess the technological potential of metal-based AM for strategic decision-making.

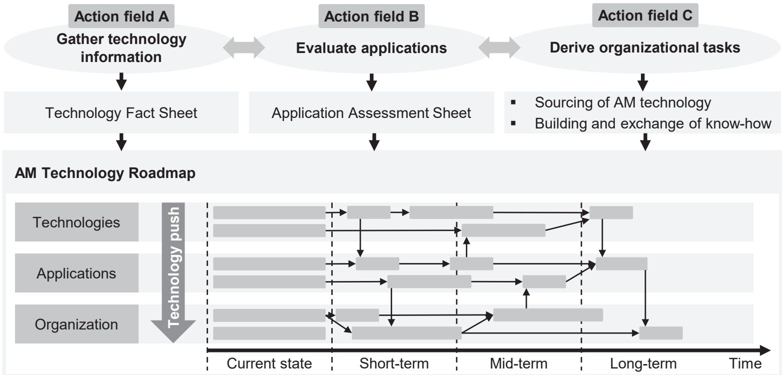

Figure 0.1: Approach to developing an AM Technology Roadmap.

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1 Introduction

1.1 Motivation

Manufacturing companies (also referred to herein as producing companies) must continually innovate to maintain and expand their market position. Innovations generate benefits for customers in form of *product innovations* or yield internal benefits in the manufacturing processes as *process innovations* (EVERSHEIM 2009). Due to the need for continuous innovation and optimization, companies must search and evaluate enabling technologies, which is task for technology management (KLAPPERT ET AL. 2011, SCHUH ET AL. 2011). Following the concept of *lean innovation*, this identification processes must be effective and efficient, which means to avoid all types of waste (SCHUH 2013).

Over the last years, several innovations in the production sector were enabled by *Additive Manufacturing* (AM) technologies (STATISTA 2018). Since the first commercial AM system, the Stereolithography Apparatus SLA-1, was patented in 1987 by Chuck Hall (YANG ET AL. 2017), AM technologies have been matured from processes for prototyping to manufacturing processes for serial parts (GEBHARDT 2016). In contrast to established, conventional manufacturing processes, AM technologies offer profound advantages. As a tool-less production process, AM offers opportunities for flexible production environments and allows to manufacture a new level of geometrical complexity. The first AM processes were based on polymers, but today metallic parts are also made additively. The most common process for metal-based AM is Laser-based Powder Bed Fusion, which utilizes a laser beam to melt a thin layer of metallic powder. Driven by the aerospace and medical sectors, metal-based AM has matured into a production process for serial applications. And since 2013, the demand for metal-based AM technologies has increased considerably (WOHLERS ET AL. 2019). Regarding the rapid development and influence on product differentiation (SCHUH 2013), metal-based AM is a *key technology* for the manufacturing of complex parts for demanding applications.

Hence, manufacturing companies are evaluating the benefits of adopting AM for their product portfolio. Whereas the aerospace sector benefits from new lightweight designs and medical applications from individualized products (NIAKI & NONINO 2018), the benefits of adopting AM are mostly not as straightforward. The main limitations to adopting AM technologies are high investment cost and a lack of internal expertise (MÜLLER & KAREVSKA 2016, MÖHRLE ET AL. 2017). According to MÜLLER & KAREVSKA (2016), only 4% of 900 surveyed companies reported having a holistic strategic approach to implementing AM. By contrast, 76% of the companies reported having *no experience* in AM. In this context, AM is just at the beginning of market diffusion. Moreover, full market diffusion is not expected within the next ten years (CAVIEZEL ET AL. 2017).

In conclusion, metal-based AM technologies are matured manufacturing processes and are considered as key technology for the manufacturing of complex parts in demanding applications. However, due to the novelty of these processes and their fast development, companies face hindrances like high invest cost and missing internal expertise, when trying to adopt these technologies. Thus, supportive approaches need to be developed to unlock the innovation potential of metal-based Additive Manufacturing.

1.2 Research Objective

The research objective of this study is a systematic approach to prepare a technology strategy for metal-based Additive Manufacturing based on the specific requirements of a company. The research objective is concretized through three key questions:

1. How should a company identify metal-based AM processes that meet its requirements?
2. How should a company identify applications in its product portfolio that benefit from AM?
3. How should a company develop a strategy to exploit the full potential of metal-based AM processes?

Based on these questions, the subdomains of the research objective were investigated. The first aspect concerns technology identification, and it is necessary to clearly describe the potential and limitations of a technology in a structured form. In addition, the maturity of AM technology must be assessed. Moreover, appropriate sources of information regarding technology potential must be identified. The selection of an AM technology is closely linked to the identification of suitable applications, which is the second aspect of the research objective. Because a production technology is only required when solving a specific production task, the identification of applications and the corresponding AM technology entails matching technology capabilities with production requirements. In addition, general benefits of AM technology must be identified, and the impact on the application must be evaluated. Besides the technical evaluation, economic aspects are crucial for the success of AM implementation. Thus, an appropriate method to identify and evaluate applications in the context of AM technology must be developed. The third part of the research objective is to develop a strategy to exploit the potential of AM technology within the company. For that, a methodical approach must be developed to support the generation of the technology strategy integrating the afore mentioned aspects. The developed methodical approach to generate a technology strategy in metal-based Additive Manufacturing should enable strategic decisions in the field of AM and thus foster the exploitation of the innovation potential of these technologies within the company.

1.3 Research Approach

The research approach is based on the general concept of *Design Research Methodology (DRM)* proposed by BLESSING & CHAKRABARTI (2009). The term *design* is defined as "those activities that actually generate and develop a product from a need, product idea or technology" (BLESSING & CHAKRABARTI 2009). The design process needs to consider all aspects of the whole product life cycle. Because the implementation of AM technologies is inherently linked to the development of products utilizing the AM benefits, the DRM framework is applicable to this research task. Moreover, following the DRM framework, supports the transfer of scientific results into practical application.

The DRM framework consists of four phases, which serve as a generalized structure to develop research findings. The four phases are the *Research Clarification (RC)*, the *Descriptive Study I (DS-I)*, the *Prescriptive Study (PS)* and the *Descriptive Study II (DS-II)*. In addition, BLESSING & CHAKRABARTI (2009) introduce the approach of a *review-based study*, which is only based on literature, and the *comprehensive study*, which uses information from literature and findings of the researcher. Combining the four phases and the study approaches, seven general types of research projects are defined in the DRM. It is emphasized by BLESSING & CHAKRABARTI (2009), that the DRM framework supports the individual, unique research approach and is not a fixed process or set of tools. Thus, the DRM framework allows for several iterations and parallel execution of phases to adopt to the specific requirements of the unique research project.